BIOLOGY

CLASS XI
PART I

BIOLOGY

A Textbook for Senior Secondary Schools

CLASS XI

PART I

MITA MAZUMDAR　DEBAJYOTI DAS　H. Y MOHAN RAM

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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FOREWORD

BIOLOGY as a discipline of science has been undergoing a thorough ecdysis in its content and methodology of teaching for quite some time. There was an unprecedented explosion of knowledge during the last three decades, which further widened the horizon of the science of life The major breakthroughs that have been witnessed are in the contemporary frontiers of biology such as agriculture, medicine, biotechnology, biomedical engineering, environmental biology, and genetic engineering.

It was thus that the National Policy on Education (1986) underlined the need of bringing about qualitative improvement in biology education as an integral part of science at all school levels To fulfil this policy directive, biology education, which pervades every walk of life, needs to be revamped urgently to meet the changing needs of our society and the aspirations of our people The present textbook of biology for Class XI is an outcome of this policy directive

In 1986 the NCERT set up an Advisory Committee under the chairmanship of Prof C N R Rao, Director, Indian Institute of Science, Bangalore, to develop instructional packages in science and mathematics from the upper primary to the senior secondary school stage Under the chairmanship of Prof H Y. Mohan Ram, Department of Botany, University of Delhi, a Biology Textbooks Development Committee was constituted to produce an instructional package for senior secondary schools. The Committee consisted of eminent scientists from leading research institutions, outstanding teachers from universities, biology educationists including the senior faculty members of the Department of Education in Science and Mathematics (DESM), NCERT, and practising school teachers.

My appreciation and thanks are due to Prof. H Y. Mohan Ram, Chairman, and all the members of the Committee for their sustained efforts to bring out this volume. I am indebted to all the participants of the National Review Workshop for their commendable contribution towards the finalisation of the manuscript of this textbook.

I would like to record my thanks to Prof B Ganguly, Head, DESM, NCERT, for making available to the Committee all facilities for holding the meetings at Bangalore and in Delhi My thanks are also due to Shri C N. Rao, Head, Publication Department, NCERT, and his publication team for quality production of this textbook. Lastly, I would like to record my appreciation to Prof. J. Mitra, Coordinator of the Committee, for his constant and unstinted help to the publication team in designing the textbook and for seeing it through the press.

Suggestions for further improvement of the textbook will be most welcome.

P. L. MALHOTRA
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PREFACE

THE National Policy on Education (1986) has emphasised the importance of science education at all levels In the new curriculum of secondary education, science will be treated as *one* area of human endeavour up to Class X After a broad exposure to an integrated treatment of certain basic concepts in science, students entering Class XI would be introduced to individual disciplines such as Physics, Chemistry, Biology, and Mathematics

The Biology Textbooks Development Committee was asked to produce Biology textbooks that would inculcate in a child a spirit of inquiry, creativity, objectivity, the courage to question, aesthetic sensibility and an abiding environmental consciousness The vast majority of Indian students are first generation learners and those who would pursue science as a career constitute a very small minority.

To prepare a book which would provide a broad-based biological knowledge, stimulate a deep interest in the natural world, teach problem-solving and decision-making skills, is no easy task

The nature of biology itself has undergone a sea change in recent times. Biology has ceased to be a mere descriptive subject With the availability of sophisticated physical tools and chemical techniques, biology has now become more analytical. Owing to high concentration of research in molecular biology, our knowledge in this field is expanding at an enormous rate Remarkable advances have been made in understanding structural organisation and functioning of cells at the molecular level. Through DNA recombinant technology, organisms have been genetically manipulated to yield new goods and services. Methods of diagnosis of diseases and disorders have been refined and speeded up. There is fresh excitement about the origin and evolution of life, working of genes, proteins, membranes and neurones and in the understanding of regulation of differentiation, reproduction, behaviour and adaptation.

The last few decades have witnessed serious global changes. Humans have been responsible for modifying their environment as no other species has done before. The population has escalated Resources have dwindled. Green chunks of our earth have been peeled off Numerous organisms have become extinct. Droughts, floods, famines and other disasters have affected many parts of the world The ozone layer has been disrupted at the polar regions and there is deep anxiety about the increased carbon dioxide content and other pollutants in the atmosphere and accumulation of toxic chemicals in soil and water bodies The anticipated changes in the world climate and rainfall patterns are causing deep concern The prospects of a nuclear holocaust are frightening

In the coming years biologists would be expected to find new strategies to meet the world needs of food and feed, safe drinking water, shelter and health Biology has a vital role to play in these efforts and to eradicate hunger, poverty and diseases, mitigate pollution, sustain natural living resources, prevent ecodegradation and improve the quality of life and ensure biological conservation In short, biologists have a stupendous task before them

The Committee has endeavoured to present biology as if people mattered An attempt has been made to connect the unity of life with the rich diversity of the organisms and their ecological and evolutionary significance

This book has been written by several authors Expectedly the styles of presentation of the text have differed Development of biological concepts has received serious attention The use of technical terms has been kept to the minimum, without sacrificing the discipline and rigour needed for a sound training in the subject. Several items of biological interest have been put in boxes in the text to arouse curiosity and thought. *These are not to be counted as contents for examinations.* The text is liberally illustrated with diagrams and photographs and is supplemented with tables. At the end of each chapter a student will find a few questions to be solved and at the end of each unit references to further reading. The book may invoke varied responses from the users. In this national endeavour, suggestions for further improvement are most welcome

Many persons have rendered help in several ways in preparing this book Lack of space does not allow me to thank all of them. It was a joy to be working with the members of the Committee and the authors, who were talented, utterly dedicated, objective, critical and cooperative. I thank the members and the authors for their friendly spirit, labour and trust in me.

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MEMBERS of the Biology Textbooks Development Committee considered it valuable to discuss the draft chapters with the subject-experts and with teachers who have to make use of this textbook in the teaching-learning situation in schools To elicit their critical views and constructive suggestions on the chapters included in this textbook, a National Review Workshop was held from 21 to 25 September 1987 at the National Council of Educational Research and Training, New Delhi Several changes have been incorporated in the chapters as a result of this interaction

The following participated in the National Review Workshop

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(*Courtesy* : Dr. M. N. B. Nair)

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Page 84 Plants provide cellulose and many other products which are used as raw materials in industry.

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(*Courtesy* : Biology Laboratory, DESM, NCERT)

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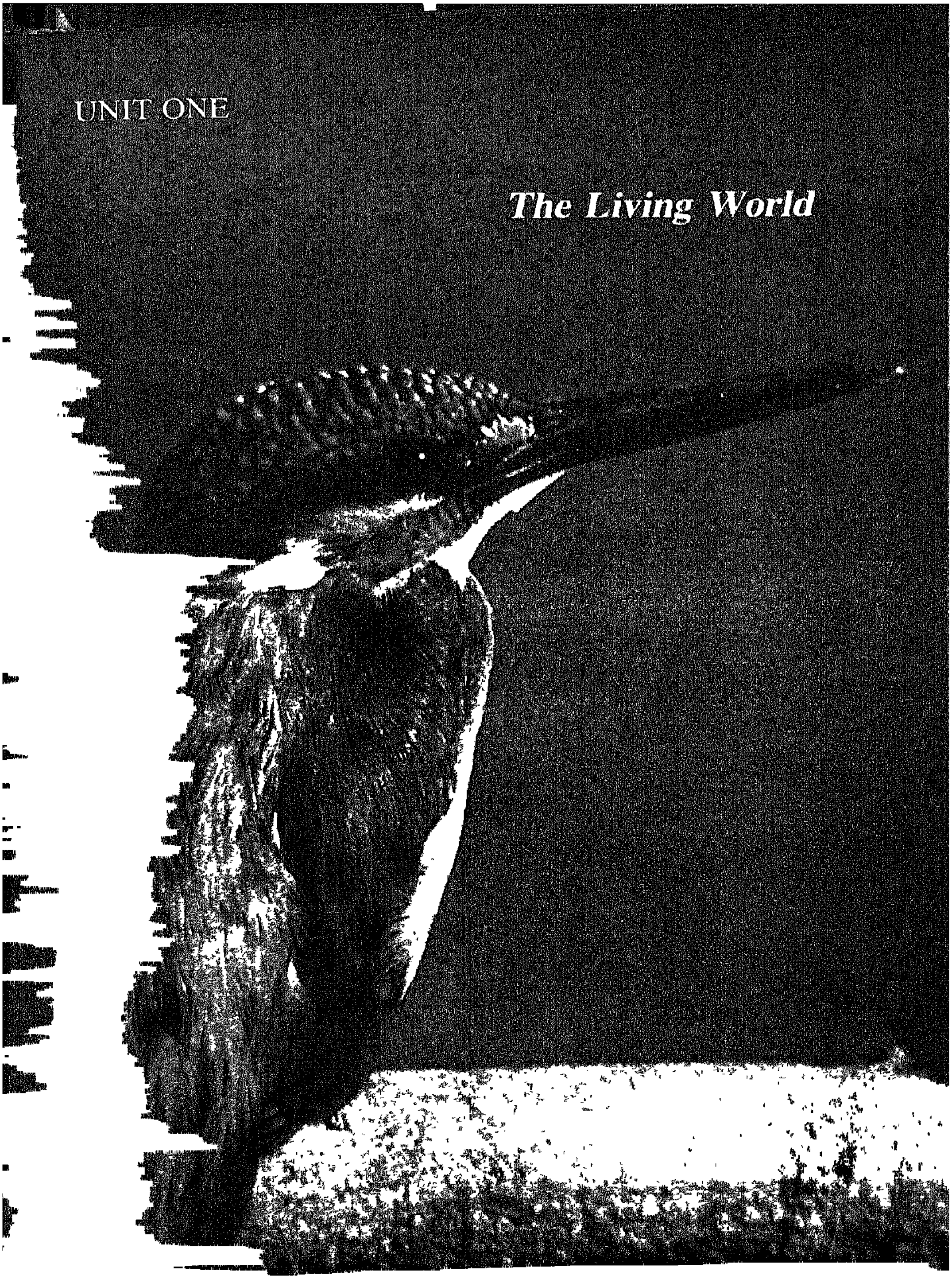
(*Courtesy* : Dr S. Chatterjee)

UNIT ONE

The Living World



CHAPTER 1

NATURE AND SCOPE OF BIOLOGY

BIOLOGY is the science of living things (in Greek *bios* means life and *logos* means study) This definition sounds simple but as we shall see later, is actually quite complex

Biology must have arisen out of human curiosity about living things, combined with the need to survive. A vast amount of biological knowledge has been built up by discoveries made by individuals and groups of scientists over a long period of time.

What do Biologists Study?

How do biologists work and what do they deal with? A strong human trait is to name, describe and classify things around us. Even the most primitive human may have practised these unknowingly. His existence depended upon his ability to recognise things he could use or avoid. Biologists continue to discover new organisms and give them scientific names and assign them to an appropriate rank. You may wonder why this activity is important. Do you know that there are approximately 12,00,000 species of animals that depend upon about 500,000 species of plants? Each year this catalogue is extended by about 15,000 types of never-before-described species. The number of plants and animals that have yet to be discovered are concealed in the jungles of tropical America, Asia and Africa. Each species is unique in its own way, whether or not it is of economic benefit to us The branch of biology devoted to identifying, naming and classifying organisms is called TAXONOMY. Taxonomy is a well-established science and there are international rules for naming organisms

The accurate description of an organism requires training and a vocabulary unique to biology The study of form and external structure is called MORPHOLOGY Internal structure may be strongly correlated with external form Structures which outwardly resemble one another may be quite different internally There are also numerous examples of organisms whose inner structure is nearly similar, but whose form is quite different (e g. ape and man). The study of the internal structure of plants and animals is termed ANATOMY. Human anatomy is a highly specialised subject. An enormous amount of information on human anatomy is known today. Details of tissue-structure are observed through various kinds of light microscopes, after following elaborate procedures such as fixing, dehydrating, embedding, sectioning, and staining. All these studies are included under HISTOLOGY.

All organisms are made of cells. The structure, function, reproduction and life history of cells play an important role in an organism's life. The study of these aspects of cells is called CELL BIOLOGY. Electron microscopy has added a great deal to our understanding of the fine structure of cells. Organisms exhibit similarity at the cellular level.

The most recent, and also the most exciting, area of biology deals with the physico-chemical organisation of biomolecules. For example, the structure of nucleic acids, the composition of proteins and the mechanism of their synthesis. It is now widely believed that the working of the cell depends upon the nature of the molecules and their interaction. This aspect of knowledge is known as MOLECULAR BIOLOGY.

Life processes are consequences of reactions that occur in an organism. The study of processes and functions (for example, respiration and digestion) associated with life is called PHYSIOLOGY.

Nearly all multicellular organisms start their life as a single cell—the zygote. By a well-coordinated sequence of divisions this initial cell becomes the embryo. The early embryo is nearly formless, and may bear no resemblance to the adult that will eventually emerge. The transformation of the embryo into its adult counterpart occurs through a series of fascinating and coordinated changes of growth and differentiation. The study of events that lead to the fertilisation of the egg, and development of the embryo is called EMBRYOLOGY. At present it is possible to study the human foetus by various imaging techniques and even detect the sex or birth defects of the unborn baby.

Organisms cannot live in isolation. They coexist and interact with other organisms and with nonliving matter such as air, water and soil. The branch of biology dealing with the relations between organisms and their environment is called ECOLOGY.

DNA is the hereditary matter in all organisms. You may have heard about genes, which are chemically DNA. What organisms are, and how they function depend on genes and their interaction with the environment. Genes are responsible for the stability or changeability of species. Curiously, organisms such as cockroaches and the *Ginkgo* tree have changed very little during the last several million years. Genetic changes in species may alter their taxonomic status. The study dealing with heredity and variation is known as GENETICS. Genetics is being increasingly applied to produce better crops, and animals and to modify microbes. Genetics also helps in understanding the principles of heredity and their role in the survival and well-being of organisms.

A fundamental aspect of biology is EVOLUTION. This may be defined as the study of continuous genetic adaptations of populations of plants and animals to the environment.

Biologists study the origin, growth and structure of organisms of the past, which have been preserved in the form of fossils. This branch of biology is called PALAEOBIOLOGY (*palaeo*, meaning old in Greek). PALAEOBOTANY and PALAEOZOOLOGY refer to the study of fossil plants and animals, respectively. Man is curious about the kind of life that may exist in outer space. This branch of scientific enquiry is named EXOBIOLOGY.

Biology and Its Relation to Other Sciences

All disciplines of science are interrelated The approach to studying biology has presently become multi-disciplinary and more broad-based than before Today a new name—Life Sciences—is often used in place of biology, to cover its wide scope The study of life sciences involves a knowledge of other basic sciences, such as physics and chemistry. This is because.

1 Living organisms are made of inorganic and organic compounds.
2 Inorganic compounds form ions in water and influence life processes
3. The acid-base equilibrium maintains the pH of living organisms.
4. Molecules move in and out of cells by diffusion and osmosis.
5 Cohesive and adhesive forces of liquids result in the phenomena of surface tension and capillarity which help in certain life processes.
6 Energy transfers and transformations are important for living cells.
7 [illegible] of responses in plants and animals

Physical and chemical sciences have techniques and analytical instruments which have been applied to advance research in life sciences. The following indicate how our recent knowledge about cells has been vastly enriched:

1 *Electron Microscope* (EM)· An instrument which can magnify a cell up to 100,000 times by employing an electron beam It has enabled us to understand the finer details of structure of the cell and its components (Fig 1 1)

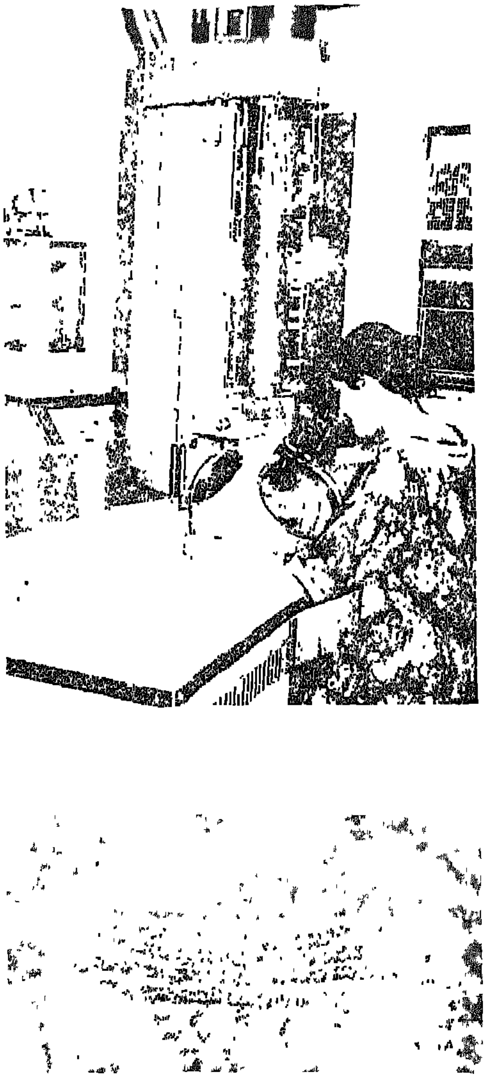


Fig 1.1 *(Top)* A young scientist using a transmission electron microscope

Golgi body as seen under an electron microscope *(Bottom)*

2. *Radio Isotopes*: Radioactive isotopes (or tracers) of elements such as C^{14}, H^3, I^{131}, P^{32} have enabled us to understand the pathways of chemical reactions occurring inside cells.

3. *Fractionation*: It is a combination of procedures by which a tissue or cell suspension is disrupted and the cell components (organelles and macromolecules) are sorted out by centrifugation and analysed

You will have an opportunity to know more about these methods later

Physical sciences are governed by a set of laws, such as the laws of gravity, magnetism, thermodynamics and so on. Biology, however, is a science of exceptions. This is because it deals with living organisms which show enormous variations and are capable of change.

EXAMPLES OF SOME EXCEPTIONS

1. Mature red blood cells of all mammals lack nuclei, with the exception of those in the camel.
2. Most roots are positively geotropic but roots of mangrove plants grow away from gravity.
3. The aquatic larval stage of the American salamander can reproduce in spite of retaining its larval form.
4. *Cuscuta*, a parasitic plant, is classified with dicotyledonous plants but lacks cotyledons.
5. DNA (deoxyribose nucleic acid) is the hereditary material with the exception of some viruses such as tobacco mosaic virus (TMV).

A student of biology must be prepared to accept exceptions Some exceptions have been explained. In other cases, the reasons for exceptions are not yet understood The quantum of unexplained phenomena in biology is much higher than in any other natural sciences

Features Common to Living Organisms

It is difficult to arrive at generalisations that are universally applicable to all living organisms Yet all living organisms have certain common features and relationships In spite of the vast diversity we observe around us, organisms are not entirely different from one another. They are interrelated All living things grow, metabolise, respond to stimuli and reproduce Life comes from pre-existing life and this genetic continuity is a fundamental principle in biology. All organisms display growth and development There is a constant interplay between the internal systems of organisms and the environment. Organisms also change over time, so that descendants are morphologically and physiologically distinct from the ancestors Many changes enable them to adapt themselves to the environment.

Why Study Biology?

The scope of biology is vast We are at a phase of learning when the pace of scientific discovery is incredibly fast. More knowledge has been gained in the past twenty years than in the past twenty centuries The following are some reasons why we should study biology

1. Biology helps us to understand ourselves better. Many questions may have occurred to you about yourself and the world around you For example:
   (a) What is meant by 'being alive'?
   (b) What factors decide our height, shape of head, colour of eyes and angle of nose? (Fig 1 2)
   (c) What is the story of our

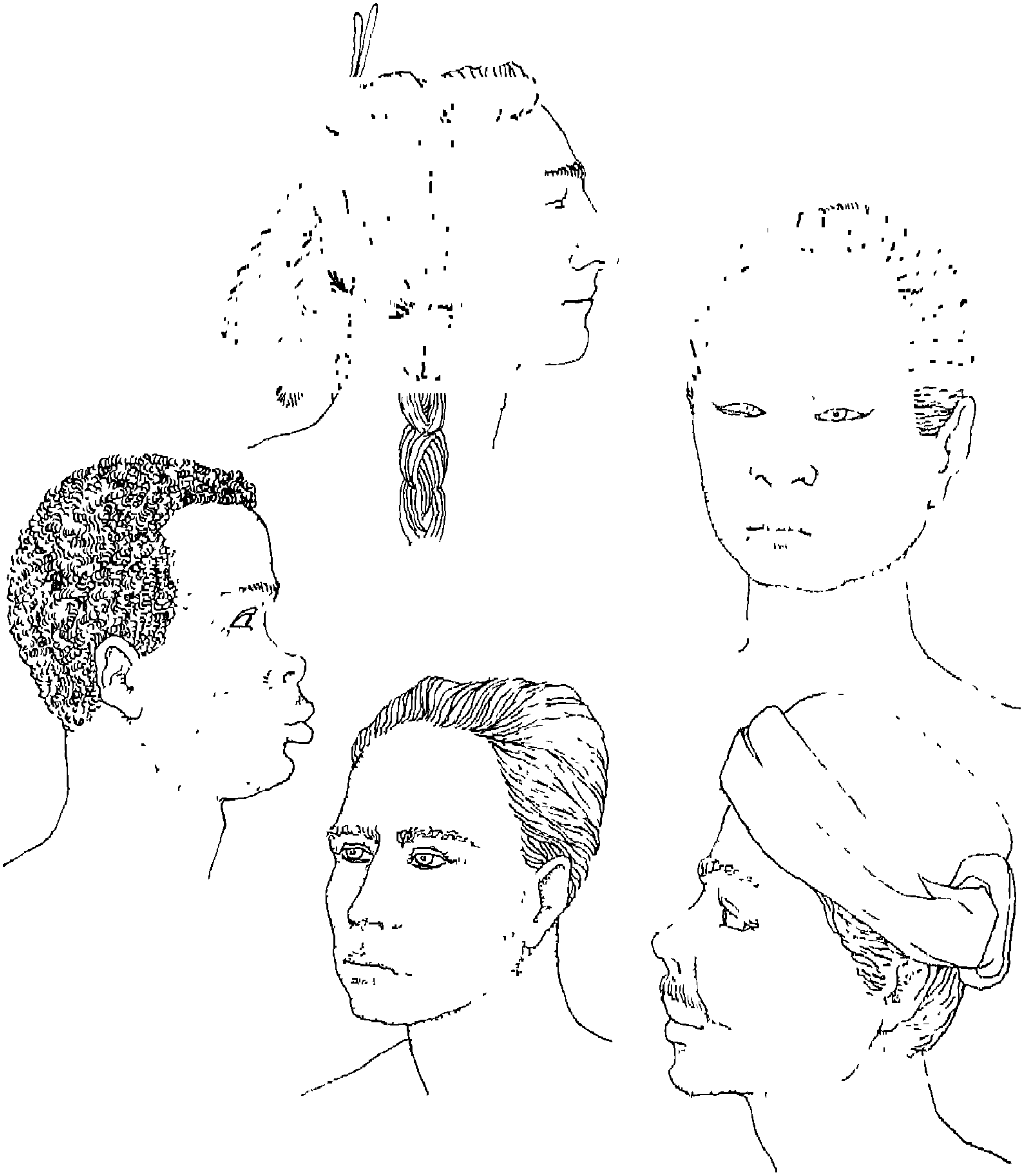


Fig. 1.2 Variation in the human head and facial features

origin? How did human beings become capable of changing their environment and using its resources in a way that other organisms cannot?

(d) What is sleep? What controls our body activities while we are asleep?
(e) What is the scientific explanation of pain?
(f) What happens to the molecules of our body when we die?
(g) How is memory stored and recalled?
(h) Is it possible to produce several thousand copies of ourselves?

Limitless number of queries occur to us every day. Many of these may have been asked by your great, great-grand parents A background of biological sciences helps us to answer some of these questions and leads to many more, which may be beyond our present understanding.

2 Biology helps us to meet our needs by utilising resources available to us

It is necessary to have scientific knowledge of the production of crops and domestic animals, their protection from diseases and pests and their utilisation to ensure our food supply We continue to depend on plants and microbes to meet our needs in shelter, clothing, energy, drugs, etc. Advances in our knowledge of medicine, surgery and microbiology have helped us to control and cure diseases and improve the quality of life

3 Solving problems is an important aspect of biology Eradication of malaria is an example of this Zoologists, medical doctors, chemists, drug manufacturers, teachers, engineers and public health workers have pooled their knowledge for combating malaria on a global scale This explains how discoveries require the collaboration of people from other disciplines if they are to be effectively used Therefore, biology is important for all of us

4 Biology teaches us that we are only a small part of this living planet and that we have the responsibility to protect and respect all other beings

5. Biology makes us aware that we do not yet understand the intricate relationships that exist among organisms in an ecosystem and that we should be cautious when we interfere with them

6. Biology warns us about the possible environmental hazards caused by our activities such as indiscriminate use of pesticides and fertilisers, destruction of forests and discharge of pollutants

7 The study of nature for its own sake is a rewarding experience Being close to nature, a biologist can observe the enormous diversity of living things that millions of years of evolution have brought forth Nature presents us with beauty at its best—the range of colours of butterflies, birds and flowers, the varied forms, pattern and symmetry of shells and corals, the gigantic trees and climbers in a tropical rain forest, the bizarre and thorny cacti in a desert. Nature's beauty has been depicted by poets and artists at all times. Increasing our knowledge and understanding

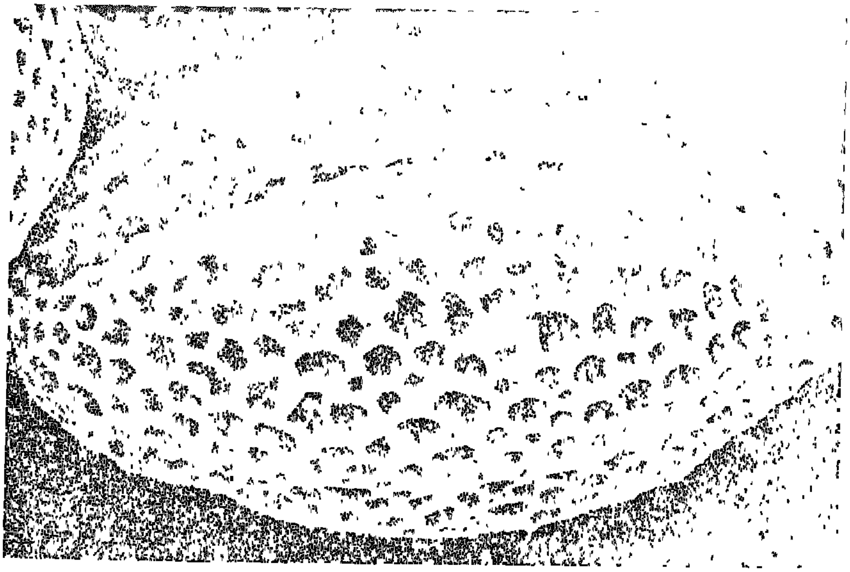


Fig. 1.3 A The surface pattern of a pollen grain as seen under a scanning electron microscope

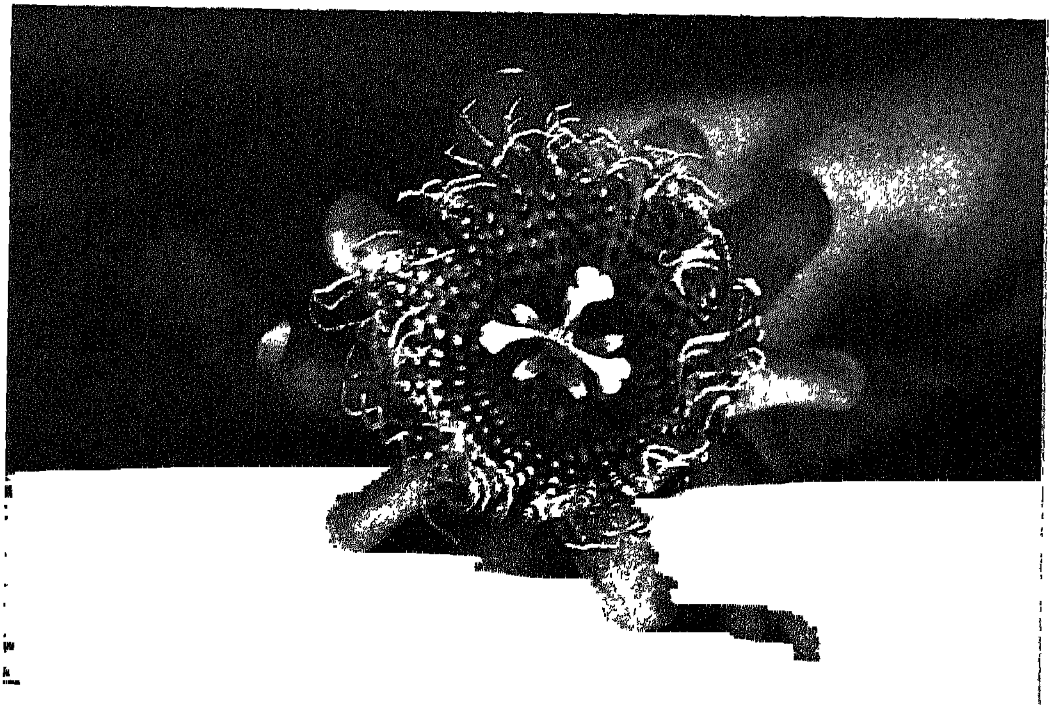


Fig. 1.3 B The colour and symmetry of passion flower

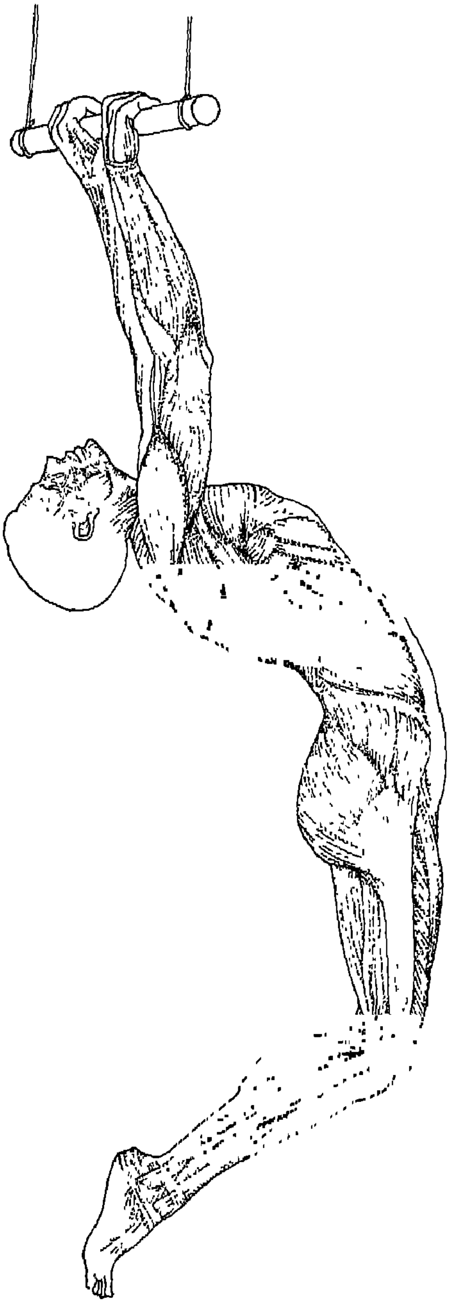


Fig. 1.3 C The beauty of human muscles in action

of nature makes our appreciation of this beauty deeper and richer (Fig. 1 3 A, B & C)

8 Biology teaches us how science is practised, how to ask questions and, through a process of reasoning and experimenting, find answers to them

What is Science and What is the Scientific Method?

Science is the study or collection of knowledge in a logical and orderly fashion and its interpretation. Rules, laws and principles are developed as scientists begin to observe patterns or relationships among a number of isolated facts Biology deals with these aspects in relation to the living world

Method of Science

There are many ways of discovering new facts about nature It is generally accepted that science is based upon a productive kind of methodology called scientific method. This method stresses accurate observation, predicting, testing, comparing and verifying with scope for correcting errors The following are steps usually observed in a scientific study.

a. *Observation*: Many enquiries begin with observation. Observation may be direct or indirect. We do not directly observe the magnetic or gravitational forces but their effects can be observed with, and sometimes even without instruments Observing is more than mere seeing. Much of our perception of the world around us is through our eyes but smell, hearing, touch and taste also help considerably Microscopes, field binoculars, tele-lenses are some tools which have augmented our powers of observation Observation is repeatable Critical observation requires training

b *Defining a Problem*. The next step is to define a problem This involves asking questions about an observation Science is able to cope with the 'whats' and the 'hows.' The question 'why' is the most difficult

> Flowering in many plants is known to be regulated by the length of the day or the night temperature. There are some perennials in which flowering occurs only once after a lapse of 12 to 120 years. Flowering and fruiting in these plants are destructive processes as the entire population perishes and a new generation must start from seeds Such plants are called monocarpic plants (once flowering) and their flowering is called gregarious flowering In the north-eastern part of India, flowering of 'mautak' (*Melocanna bambusoides*) and 'rothing' (*Bambusa tulda*) bamboos occurs once in 48 years. Flowering is accompanied by an enormous increase in the population of several species of rats. The rats consume the bamboo grains and with the exhaustion of the food supply, they attack the standing crops such as rice and maize in the neighbourhood, causing extensive devastation A famine ensues, affecting the people in these parts We neither know the fundamental basis of gregarious flowering, nor the nature of the signals that stimulate the over-production of populations of rats, nor the cause of the death of bamboos

c *Making a Hypothesis:* This step involves making a guess or predicting the possible answers to a question, selecting known facts and correlating them. A hypothesis often consists of a group of interconnected statements or assumptions that give a possible solution to a problem. To form a hypothesis is not easy Consider the following situation.

You observe that a plant kept on a window sill grows towards light For your question, "What makes plants bend towards light?", a ready answer that seems to be logical is "Because they need light for growth." This kind of answer suggests that plants 'know' that they need light. Such presumptions about natural phenomena are termed 'teleological.' Teleological explanations are just one kind of explanation which scientists do not accept because they do not lend themselves to verification Another hypothesis could be that stems grow more on the shaded side than on the illuminated side, resulting in bending towards the light outside the window. This can be experimentally verified and is therefore accepted by scientists This raises the further question — "What causes unequal growth?" Another testable hypothesis is made to explain this Further experimentation is needed to test this hypothesis also Scientific knowledge expands in this way

d *Testing or Experimenting*. Whether or not a prediction is correct, needs testing It is not always easy to devise a suitable test or a good experiment. When an experiment fails, the causes need to be analysed and the experiment replanned. An ideal experiment involves proper designing including control, appropriate materials and a well-defined procedure. Observation, analysis, interpretation of data and inference, along with suitable precautions should also form part of the experimental process. You will have many opportunities to perform experiments in your school laboratory.

Why have a control?

An important component of an experiment is to have a control. Consider an experiment to demonstrate that germinating seeds release carbon dioxide during respiration. The experiment is generally performed by placing germinating seeds in a flask and connecting it to a tube containing lime water and fitted with a cork. Lime water turns milky with carbon dioxide evolved by the germinating seeds. A control experiment would consist of a similar set-up, but with non-germinating seeds (non-germinating seeds produce so little carbon dioxide that it is difficult to prove its presence by a chemical test). Lime water will not turn milky in the control. Thus it is shown that the germinating seeds produce carbon dioxide while non-germinating seeds do not. The role of the control therefore is to establish the validity of an experiment. It is important to remember that a hypothesis based on experimental data without proper control cannot be held to be valid.

Some types of scientific studies cannot possibly have a control. For example, we cannot have a control when we are observing the actual movements of a particular planet along an orbit. Some facts are established by repeated observations only. Again, we know that the sun rises in the east, because no one has observed anything other than this for the past so many centuries. Thus facts established by accurate and repeated observations do not require further verification.

c. *Theorising.* On the basis of experiments that yield repeatable results (necessary for proving validity), or from the understanding gained by analysing a large body of biological data, a theory may be formulated. However, every experiment need not contribute to theorisation.

Accumulation of data often involves long periods of time. Some discoveries are made much ahead of their time and have to await subsequent findings to provide the basis for a theory. For example, the cell was discovered by Robert Hooke in 1665 but the Cell Theory was formulated by Schleiden and Schwann only in 1838–1839.

Theories are subject to change

This is because fresh information is gathered or alternative interpretations are made. Darwin's theory of natural selection has been modified in the light of advancements in different fields of biology. Alternative theories on evolution are also now available, e.g. Kimura's theory.

One interesting phenomenon often associated with scientific method is SERENDIPITY. This is the faculty of making interesting discoveries unexpectedly or by accident. The chance observation of an infected petri plate by Alexander Fleming in 1928 led to the development of antibiotics, their manufacture and large-scale use to conquer diseases caused by microbes.

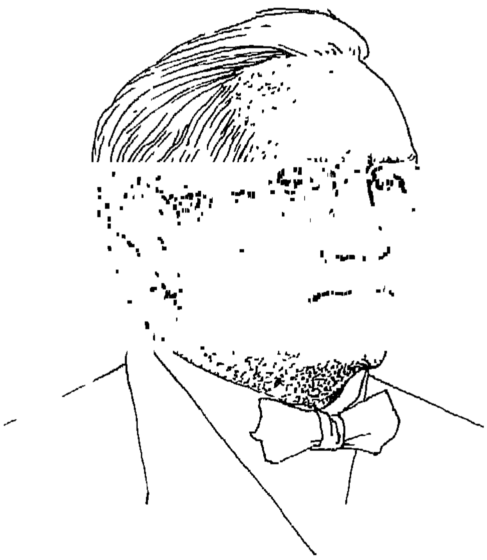


Fig 1 4 Alexander Fleming, the discoverer of penicillin

Alexander Fleming (1881–1955) was studying the bacterium *Staphylococcus* that causes throat infection He was growing this organism in petri plates on agar medium It is a common observation that such culture media often get contaminated with other microbes Fleming observed contamination of a blue-green mould *Penicillium notatum*, in one of his culture plates Normally, contaminated cultures are discarded, but Fleming retained this particular plate It looked different, as the normal cloudy appearance resulting from bacterial growth was absent. The presence of a clear area round the mould indicated that bacterial growth had been inhibited Many other bacteriologists had also made the observation that moulds inhibit bacterial growth But Fleming wanted to know why Further investigation led to the discovery that a toxic substance produced by the mould inhibited bacterial growth. Fleming named this substance penicillin (1928–29) He made the cautious statement that "penicillin might prove to be an effective antiseptic agent against penicillin-sensitive microbes" Subsequently, tests showed that penicillin was not toxic to human beings, and thus it became one of the most useful antibiotics During World War II, penicillin proved to be of tremendous value in controlling infections among wounded soldiers

Although serendipity refers to chance discoveries, we may observe, as Pasteur did many years ago, that "chance favours the trained mind."

Ideas in science are often generated by sudden flashes Intuition and conjecture also play a role in scientific studies

Method of Science as a Part of Life

The method of science is not limited to the laboratory, but operates in the way we do things. We often apply science unknowingly in our daily lives Consi for example washing our hands before e ing, avoiding stale food, storing win clothes with *neem* leaves or with moth bal removing shoes before entering a kitch boiling milk and using salt and oil in pickl Customs such as these have a scienti basis

Whatever be our occupation, it important to develop and maintain scientific attitude This attitude is a set human values These include a deep se of curiosity, critical observation, keenness to get to the root of a problem, fearlessness, freedom from bias or prejudice and willingness to change on being convinced that change is necessary. These constitute what is termed the scientific temper. Scientific approaches may vary but the basic attitude does not.

Application of the scientific method has helped in solving many biological problems and will continue to do so.

In recent years, the frontiers of biological knowledge have expanded enormously as new techniques and refinements in instrumentation for analysis have become available. Yet, scientific method is a human activity and scientists are fallible. They often make mistakes but these are corrected by the proper application of scientific method.

Growth of Scientific Knowledge

Scientific knowledge is the outcome of efforts of a great many people over the centuries. You would not consider many of them as scientists in the present day terminology. We owe our present comforts to discoveries made by persons many of whom have remained unknown and unpraised. For instance, who discovered the use of fire, invented the wheel or started agriculture? These are the people who set the stage for science.

Let us remember that science does not claim to understand or interpret every natural phenomenon. There are many areas in which our present understanding is meagre. Scientists believe that there is nothing like 'ultimate truth' or 'knowing everything.' That is not even the purpose of science.

What This Book is about

The account of biological knowledge in this textbook is far from complete. But that should not stop you from asking questions and questioning the answers. In the opening unit of your textbook, an effort has been made to view the living world with a 'scientific eye' and share with you some basic biological concepts. Other units in this volume explain the unity and diversity of life, organisms in relation to their environment, and the multicellular way of plant life. Next year you will learn about the multicellular way of animal life, continuity of life, origin and evolution of life. Also, at the end, a whole unit is devoted to the applications of biology which will be of special interest to you. It presents the wide range of professional opportunities that are available to a student with background of biology.

BIOLOGISTS HAVE A WIDE CHOICE OF CAREERS

Here are some disciplines which are closely related to biology. If you have a good background in biology it will help you to choose any of these fields. The list is only illustrative and not exhaustive.

Anthropology	The science of man and mankind, including the study of the physical and mental constitution of man, his cultural development, social conditions, as exhibited both in the present and the past

Agronomy	Management of farms and the science of crop production
Soil Science	A study of soil, involving its structure, type and dynamics
Pathology	The science dealing with the nature of diseases, their causes, symptoms and effects
Breeding	To produce or procreate improved varieties by selective mating
Veterinary Medicine	Deals with the diseases of domesticated animals and their health care
Entomology	A branch of zoology which deals with the structure, habits and classification of insects
Fishery	The occupation or industry of catching fish or other products of the sea, lakes or rivers
Poultry Science	Science dealing with domestic fowls, such as chickens, ducks and geese
Sericulture	The breeding and treatment of silkworms for producing raw silk
Apiculture (मधुमक्खी)	The rearing of bees, beekeeping, especially for commerical purposes
Forestry	The science of developing, cultivating and conserving forests
Dairy Technology	The application of science for the manufacture of milk products
Microbiology	The science dealing with the structure, function, uses, etc , of microscopic organisms
Pharmacology	The science or knowledge of drugs and preparing medicines
Psychology	The branch of knowledge which deals with the human mind, its behaviour and

	mental qualities
Pharmacy	Preparing and compounding medicines and dispensing them according to the prescriptions of medical practitioners
Forensic Science	Application of scientific knowledge to questions of civil and criminal law (includes use of finger-prints, blood typing, identification of narcotics, etc)
Medicine	The science of treating diseases with drugs or curative substances
Surgery	The branch of medicine, involving physical operations to cure diseases or injuries to the body
Human Reproductive Biology	The science of understanding and regulating human reproduction
Nutrition	Study of the nourishment of human beings or other organisms
Physiotherapy	The treatment of diseases, bodily weaknesses, or defects by physical remedies, such as massage and exercise
Occupational Therapy	A method of treatment of convalescents and the physically handicapped utilising light work for diversion, physical exercise or vocational training
Genetic Engineering	Involves genetic manipulations to produce an organism with a new combination of inherited properties
Biomedical Engineering	Production of spare parts for man, implants, artificial limbs, heart-lung machines, etc.
Food Technology	Processing and preservation of foods

SUMMARY

Biology, the science of living things, is a vast subject. Curiosity and the human instinct to survive were the main factors that resulted in the amassing of biological knowledge over the years. Biologists deal with various aspects of the living.

Describing and classifying living things is a basic human trait. Biologists are continually engaged in these activities as the inventory gets extended every year by thousands of organisms that have yet to be named and classified. This is taxonomy. Morphology deals with accurate description of form and external structure. The study of internal structure is anatomy. The branch of biology devoted to the detailed observation of tissue structure is known as histology. The study of structural and functional aspects of a cell facilitated by the electron microscope and other sophisticated tools comes under cell biology. The aspect of biology dealing with molecules of life and their interactions is termed molecular biology.

Physiology deals with life processes. Events leading to fertilisation and development of the embryo are studied under embryology. Ecology is concerned with the relations between organisms and their environment. The branch of biology in which heredity and variation are investigated is named genetics. The study of continuous genetic adaptations is termed evolution.

Sciences are interrelated and biology requires a knowledge of physics, chemistry and other basic sciences. The understanding of life in all its aspects, using physico-chemical techniques, has given rise to a broader term 'life sciences' for biology.

It is difficult to formulate universal laws in biology as there are so many exceptions. Living organisms show enormous variations and are capable of change. Nevertheless, some generalisations applicable to the vast diversity of living organisms are growth, metabolism, responsiveness and reproduction. All living organisms are capable of interaction with one another and with the environment, and have the potential to evolve.

Biology is important for all of us. It helps us to understand ourselves better and to realise the meaning of being alive. It enables us to meet our needs through judicious use of resources, eradicate diseases and check the degradation of our environment. Biology makes us aware of our role on this planet, reminds us of our limitations in understanding the ecosystems and enhances our appreciation of the beauty of the rich and varied living heritage. Biology teaches us how to practise science.

Scientific method begins with accurate observation. Raising questions such as what, how and why of an observation and defining the problem constitute an important step in this method. Hypothesising involves predicting possible answers to the questions raised. The predictions are tested by experimentation. This involves collection of data, their analysis and interpretation. Experiments performed without a control are not valid. However, in some scientific studies, facts are established on the basis of repeated observations. A large body of data from observations or results of repeatable experiments provide the basis for a theory. A theory may or may not be acceptable and is also subject to change. Serendipity, intuition and conjecture also play an important role in scientific studies.

The method of science is not limited to the laboratory. It often forms a part of our everyday life. It is important to develop a scientific attitude and a scientific temper. These include a deep sense of curiosity, critical observation, keenness to discover the truth, fearlessness, freedom from bias or prejudice and willingness to change on being convinced

A large number of people, both scientists and non-scientists, have contributed to the growth of biology The quantum of unexplained phenomena in biology is very large. A background in biology will not only equip you to find answers to unknown questions, but also enable you to choose from a wide range of careers

QUESTIONS

1 Out of the following, select the statement(s) that appear correct in your judgement.
   (a) Morphology and anatomy cannot be interrelated because the former deals with external form, the other with internal structure
   (b) They are interrelated because form and strucutre are complementary to each other
   (c) A tall tree is an example of anatomy determining morphology
   (d) An organism containing dead tissues must be considered dead

2 Match the items in the two columns appropriately

(a)	Histology	(a)	I have the same colour of eyes as my mother
(b)	Ecology	(b)	My body maintains a constant temperature
(c)	Physiology	(c)	I have observed a stained preparation of a section of leaf under the microscope
(d)	Genetics	(d)	We and apes have common ancestry
(e)	Evolution	(e)	A cell divides into two by mitotic division.
(f)	Cell biology	(f)	I often find grasshoppers and frogs in the same place

3. Explain briefly what is meant by scientific method

4. Enlist the biological, physical, and chemical principles involved in explaining the lifting of a heavy weight by man.

5 Suggest a control for each of the following
   (a) The enzyme α amylase specifically acts on starch
   (b) Photosynthesis occurs only in the presence of light
   (c) Seeds must be soaked in water before they can be germinated

6 Expalin the term 'Serendipity ' From your knowledge of other sciences, give some examples of the phenomenon.

7. Advances in biology have been possible because of the development of new physico-chemical techniques and instruments Apart from the examples mentioned in your text, can you think of others and explain the nature of their utility in biology?

8 Why is biology considered a science of exceptions? Explain List any five biological aspects which have so far eluded our understanding or explanation

9 Can you think of a few major biological problems in which biologist alone will not be able to find solutions, but will have to work in close collaboration with other scientists?

CHAPTER 2

BEING ALIVE—WHAT DOES IT MEAN ?

IT has been said that biology is the science of living beings. Having understood the meaning of science and its method, let us analyse what is meant by living.

Living beings are called organisms, whether they consist of one cell or many. Living beings exist along with nonliving objects on this earth. Both are made up of the same elements. They are also subject to the same physical laws, such as those of gravitation, magnetism, action and reaction. Then, how are the living different from the nonliving? Is there a clear line of demarcation between them?

Living beings are unique, because they present a characteristic level of organisation. The levels of organisation of matter differ between the living and the nonliving

WHAT IS ORGANISATION ?

The term 'organisation' has many meanings, depending on the context in which it is used. It may be explained as the manner in which smaller components of any structure, system or a situation are arranged in a hierarchy to coordinate with one another towards a goal.

Consider the following levels of organisation, beginning with atoms.

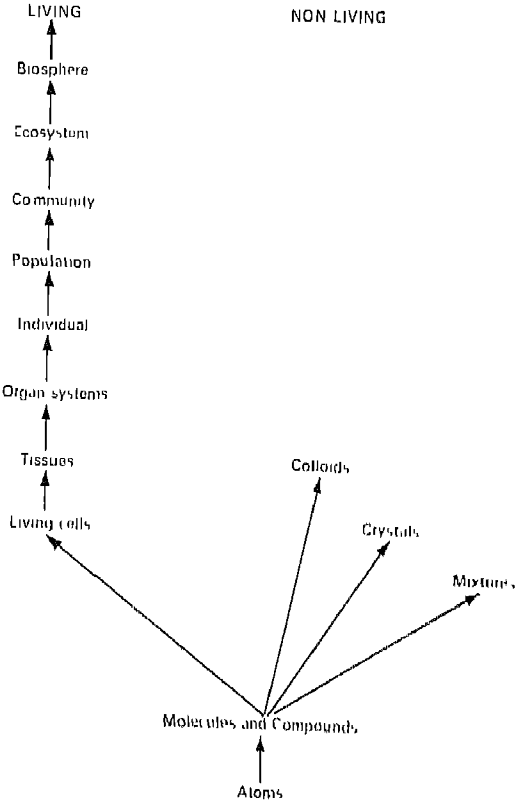


Fig 2.1 Levels of organisation

In the living, the organisational levels continue up to very complex systems that include the entire livable surface of the earth—the biosphere You have studied some aspects of hierarchy in organisation in your early classes and will learn more in this chapter

Two interesting points are:

1 The differences between living and nonliving at a molecular level became established *very early* in geological history
2. Among the living, organisation became more and more complex, beyond the individual level

The important operations that regulate organisation at different levels are aggregation, interaction, equilibrium and change. Aggregation is the act of collection or getting together to form a whole Interaction refers to the relationships between the participants in the aggregate This results in a balance or stability (equilibrium), or it may also result in a change and hence a variation Consider the following examples:

(i) Hydrogen and oxygen atoms aggregate and interact to form a stabilised structure of the water molecule The same atoms can also aggregate and interact in a different manner to produce the molecule of hydrogen peroxide.

(ii) When we breathe, an aggregate of organs like the nose, wind pipe, lungs, rib cage and diaphragm, (forming the system of respiration) intereact with one another, to produce breathing movements in a balanced manner

Simply putting together all the elements in a mixture in the right proportions, and supplying them with energy does not create life The mystery of being alive, which is difficult to explain, lies in the highly complex way in which living matter is organised.

An organism has its identity as an individual and also as a part of a population, community, ecosystem and biosphere Let us first understand "being alive" at the level of the individual·

THE LIVING INDIVIDUAL

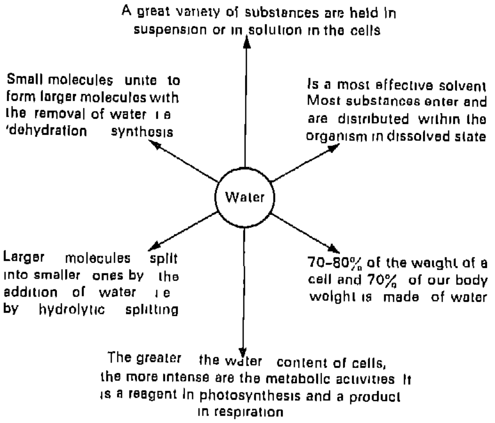
In spite of all our knowledge, it is difficult to explain life solely in terms of laws of physics and chemistry. Life is something special We must remember that organisms behave in ways more complex than their component parts The goal of biology is to interpret the living world We shall examine some essential aspects of living organisms such as their molecular basis, energy changes, reproduction, adaptation and ultimately their death. We shall begin with the molecular basis of life, since it is at this fundamental level of organisation that organisms differ from the nonliving

The Molecular Basis

The famous biologist Linus Pauling stated that, "Life results due to a relationship of molecules and is not a property of any one molecule." The earlier approach to understanding life was to begin with the gross structure of the organism and then study the finer details. The present approach is to understand the molecular structure and activities first, and then correlate them with the gross structure and function of the organism At the molecular level, organisms have the following characteristics:

(i) There is predominance of carbon, hydrogen and oxygen in the living, and hence molecular organisation is basically organic in nature. The organic substances found in nature such as coal and petroleum can all be traced back to organisms that lived in the past A relatively simple organic molecule such as glucose can be found only in the living The molecular organisation of the nonliving mostly consists of small molecules such as gases, salts, ores in mines and some forms of crystals

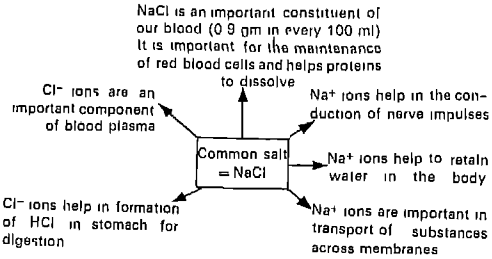
(ii) Both small (micromolecules) and large (macromolecules) molecules are important to life. Some small molecules such as water, common salt, sugar are so common that we tend to take them for granted Their role in 'being alive' is shown below


A great variety of substances are held in suspension or in solution in the cells
Small molecules unite to form larger molecules with the removal of water i e 'dehydration synthesis
Is a most effective solvent Most substances enter and are distributed within the organism in dissolved state
Water
Larger molecules split into smaller ones by the addition of water i e by hydrolytic splitting
70–80% of the weight of a cell and 70% of our body weight is made of water
The greater the water content of cells, the more intense are the metabolic activities It is a reagent in photosynthesis and a product in respiration

Water has many other uses for the living in its solid and vapour forms Above all, life originated in water

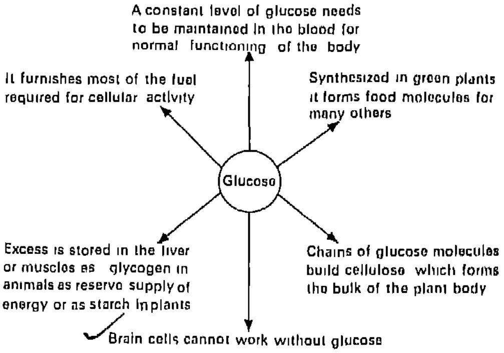
Usefulness of Common Salt

Ions of sodium and chloride play important roles in living processes of animals


NaCl is an important constituent of our blood (0 9 gm in every 100 ml) It is important for the maintenance of red blood cells and helps proteins to dissolve
Cl⁻ ions are an important component of blood plasma
Na⁺ ions help in the conduction of nerve impulses
Common salt = NaCl
Na⁺ ions help to retain water in the body
Cl⁻ ions help in formation of HCl in stomach for digestion
Na⁺ ions are important in transport of substances across membranes

You may have observed that a saline drip is given to patients suffering from a severe loss of salts from the body as in cholera, dysentery, vomitting, etc.

Importance of Glucose


A constant level of glucose needs to be maintained in the blood for normal functioning of the body
It furnishes most of the fuel required for cellular activity
Synthesized in green plants it forms food molecules for many others
Glucose
Excess is stored in the liver or muscles as glycogen in animals as reserve supply of energy or as starch in plants
Chains of glucose molecules build cellulose which forms the bulk of the plant body
Brain cells cannot work without glucose

(iii) Macromolecules such as carbohydrates (sugars and polysaccharides), lipids or fats and proteins (structural proteins and enzymes) exist only in living beings in nature The macromolecules vary from several hundred to several hundred million molecular weight units. Macromolecules are formed by polymerisation (joining of repeating units) of smaller units. Cellulose and starch are polymers of glucose. DNA is also a polymer There are 20 different amino acids that occur as regular constituents of proteins Several kinds of proteins can be formed by different combinations of amino acids. Of all macromolecules found in the cell, the proteins are probably the most diverse chemically and physically The size (molecular weight), shape and function of proteins are determined by the number, type and distribution of amino acids present in the molecule For example, the hormone adrenocorticotrophic hormone (ACTH) consists of only 39 amino acid units (molecular weight 4500) and hemocyanin in the blood of snails consists of 8200 amino acids (molecular weight 910,000). Interestingly, the activities of small molecules are regulated by macromolecules such as enzymes and DNA.

(iv) An increase in the variety of molecules available in a cell provides a greater opportunity for a wide range of chemical reactions.

It is estimated that there are over 5000 different chemicals in a cell The number of chemical reactions that occur in a cell are several times this number The major chemical reactions may be grouped in two categories—the 'building up' reactions or *anabolism* and 'breakdown reactions' or *catabolism*

For example:

$$6CO_2 + 6H_2O \xrightarrow[\text{enzymes}]{\text{light energy} \quad \text{chlorophyll}} C_6H_{12}O_6 + 6O_2 \quad \text{- Anabolism}$$

carbon dioxide water glucose oxygen

and

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzymes}} 6CO_2 + 6H_2O + \text{energy} = \text{Catabolism}$$

glucose oxygen carbon dioxide water

A wide range of chemical components of a cell and their reactions are known. Yet it has not been possible to create a cell Biologists are trying to understand the manner in which these molecules and reactions are organised and integrated in a cell to make it 'living.'

Life as an Expression of Energy Changes and Exchange of Matter

All matter, living or nonliving, contains energy Energy is the capacity to do work Energy can neither be created nor destroyed. This is the first law of thermodynamics.

Whenever work is done energy is either transformed, transferred or both Such changes in energy occur continuously in a living cell. The most important example of energy transformation in nature is that of light energy into chemical energy

Light energy from the sun

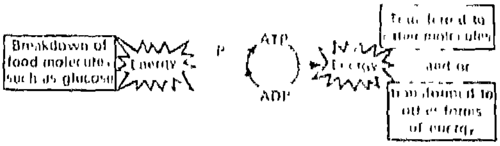
↓

By photosynthesis in green cells

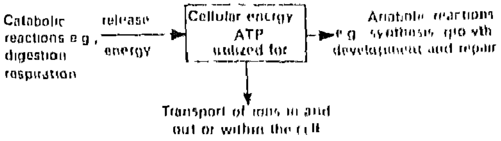
↓

into chemical energy in the form of food molecules

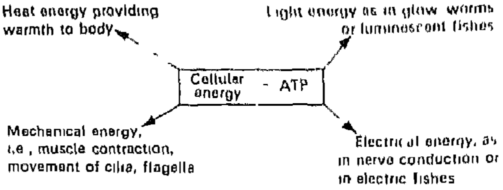
Food molecules,such as glucose, break down and release energy This energy is then stored as adenosine triphosphate (ATP) molecules ATP molecules are the available source of energy in all living cells. Most cellular processes involve the transfer of energy from ATP molecules to other molecules Some reactions involve transformation of chemical energy to other forms such as electricity, light and heat The above can be summarised as:


Breakdown of food molecules such as glucose
Energy
P
ATP
ADP
Energy
Transferred to other molecules
and or
transformed to other forms of energy

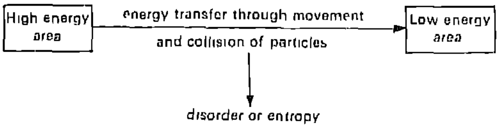
Examples of energy transfer


Catabolic reactions e g , digestion respiration
release energy
Cellular energy ATP utilized for
Anabolic reactions e g synthesis, growth development and repair
Transport of ions in and out or within the cell

Examples of energy transformations


Heat energy providing warmth to body
Light energy as in glow worms or luminescent fishes
Cellular energy - ATP
Mechanical energy, i.e , muscle contraction, movement of cilia, flagella
Electrical energy, as in nerve conduction or in electric fishes

According to the second law of thermodynamics, any system, including the universe, when left to itself tends to increase ENTROPY Entropy is a term that may be regarded as DISORDER or RANDOMNESS Energy has a tendency to be evenly distributed It gets transferred from high energy areas to low energy areas During this distribution, there is collision of particles natural to any kind of movement This collision results in disorder



As a result of this disorder some energy is lost in the form of heat and it cannot be restored to do useful work (Fig 2 2) Thus energy transfers or transformations are never one hundred per cent efficient When such a loss of energy occurs repeatedly in a series of energy-changing reactions, there is an increase in entropy An increasing degree of entropy will lead to death of a cell or the organism, unless the loss is made up. In a living system, the loss is made up through the input of free energy (= usable energy) Free energy minimises entropy. From where does the organism obtain its free energy? It is derived from the environment, either directly from sunlight as in autotrophic plants, or in the form of food molecules This explains why an organism cannot be isolated from its environment

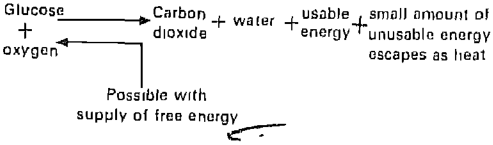
Consider the following reaction

Glucose + oxygen

↓

Carbon dioxide + water + energy

The reverse reaction is theoretically possible, but does not occur, unless free energy is supplied to it.

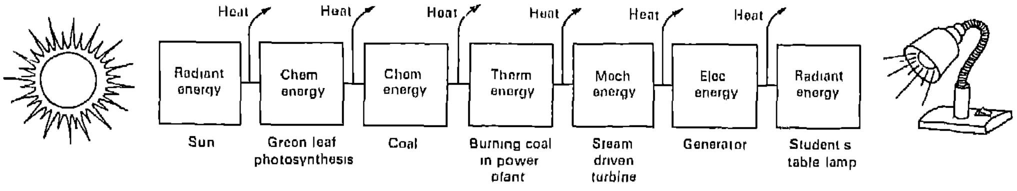

Glucose
+
oxygen
Carbon dioxide
+ water +
usable energy
+
small amount of unusable energy escapes as heat
Possible with supply of free energy

Open System, Steady State and Homeostasis

A living organism must have constant access to free energy or else its organisation will collapse over time, leading to death. Such a system which has a continuous inflow of energy, directly or indirectly is called an OPEN SYSTEM.

A CLOSED SYSTEM is one in which there is no exchange of matter with the surroundings An open system is also a system in a STEADY STATE (Fig 2.3). You may wish to know the meaning of this statement. In a steady state, the rate of input of matter and energy equals that of the output For example, a living organism must be continually supplied with inputs such as water, oxygen, energy and a variety of materials. Without these, the organism cannot maintain itself. There must also be an output of carbon dioxide, nitrogenous

Fig 2.2 Energy can be changed from one form to another With each change a certain amount of energy is lost as heat



wastes and heat which are products of chemical reactions, and which would be harmful to the organism if they were allowed to accumulate

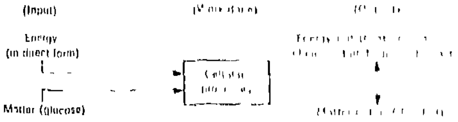


Fig 2 3 An open system is a system in steady state

The living steady state has a self-regulatory mechanism. Such a self-regulated system is said to be in a state of HOMEOSTASIS All organisms have some capacity to maintain their internal conditions so that the chemical reactions in their cells continue without interruption in spite of changes occurring in the external world. The internal environment of the organism is maintained at an optimum range for cellular functions (i.e physiological equilibrium). In a multicellular organism all the cells, with the exception of specialised reproductive cells contribute to the maintenance of optimal conditions inside the body

A large number of examples from everyday life can be cited to explain the operation of homeostasis

(i) When you enter a darkened cinema hall from bright light you can see almost nothing at first. Within a few seconds you are able to adjust your sight to the dim light and move about.

(ii) Your heart normally beats at a constant pace of 72 times per minute. When you run up a flight of stairs, you can feel your heart thumping. The heart beats faster because of the need for increased and faster blood supply to the tissues which have done extra work. But after some time the normal rate of heart beat is restored

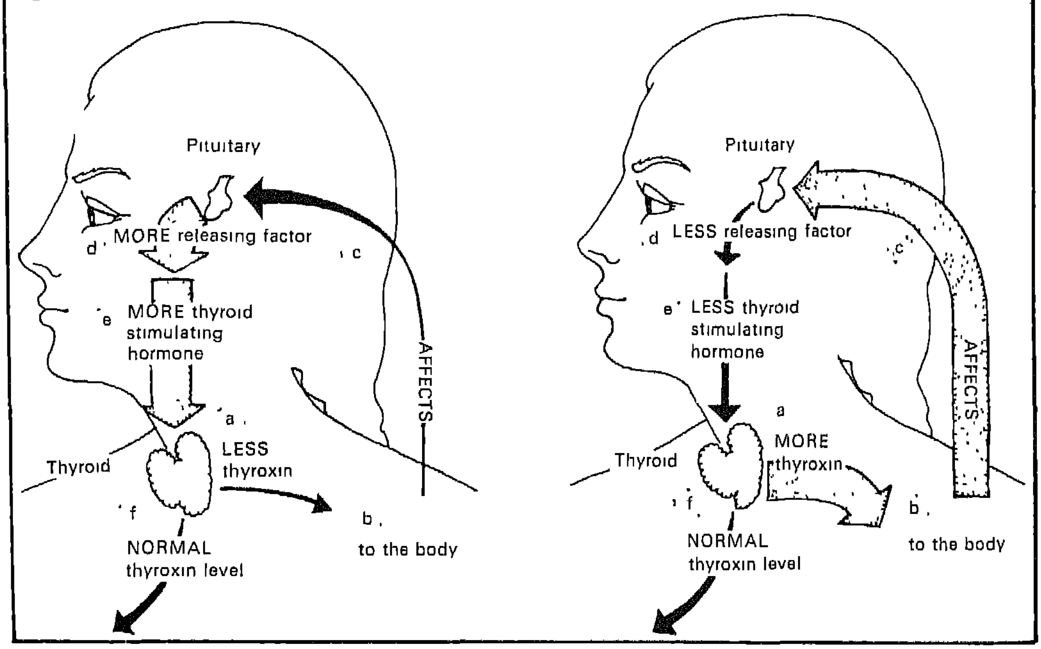
(iii) After vigorous exercise your body temperature rises You sweat profusely. Cooling by evaporation of sweat brings down the temperature Similarly in winter the skin contracts because heat has to be conserved

(iv) If you have sustained a minor cut or have a mild infection, there is temporary discomfort Your body has its own mechanism to counter these, and to help you feel normal in a short time You will learn about defence mechanisms of the body later

Most homeostatic mechanisms in the organism work through feedback systems. For example, levels of the hormone thyroxin are maintained in blood through the interaction of pituitary and thyroid glands which secrete thyroxin Thyroxin has the function of regulating the rate of chemical activities of cells.

Although homeostatic mechanisms are common to all forms of life, they are difficult to understand. For example, we do not clearly understand what starts off cell division; what factors determine when cell division should stop; how many cells of what size should be formed, and which cells should differentiate into what kind of tissues, and so on. Different types of cells are present in plant and animal bodies. They have different types of metabolic reactions. Yet, not only do they maintain homeostasis at the cellular level, but all the cells, tissues and organs coordinate themselves and maintain homeostasis in the organism as a whole. Cellular steady states form the basis of all steady states and also of adaptation and self-perpetuation. Homeostasis is not restricted to the individual. It operates at all levels of the living hierarchy and contributes to balance in nature You will have an opportunity to learn more about these aspects later in the book

Fig. 2 4 The feedback mechanism between the pituitary and thyroid glands
To understand the mechanism, begin at in each diagram and follow the sequence of letters



Reproduction and Survival

Individual organisms die from various causes such as predation or by failure to replace molecules to run the machinery of life If a species is to survive, its members must replace those that die To produce more of one's own kind is characteristic of the living Millions of years ago, the macromolecules such as DNA developed the capacity to duplicate themselves The perpetuation of organisms is possible because of reproduction The statement "nothing lives forever, yet life continues," illustrates the role of reproduction in nature

A cell requires instruction for reproduction This is contained in DNA, the molecules of heredity. DNA is the storehouse of all information required for growth, differentiation and other life processes This information is like the "blue print" that an architect prepares to construct a building The message from the DNA is used by the machinery of the cell to form proteins Some proteins function as enzymes, which help to convert nonliving matter into living matter This entire process is self-regulated in a cell.

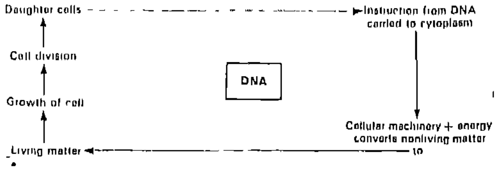

Daughter cells
Instruction from DNA carried to cytoplasm
Cell division
DNA
Growth of cell
Cellular machinery + energy converts nonliving matter to
Living matter

Fig. 2.5 DNA is the storehouse of all cellular information

Viruses are unique They have the genetic material but no machinery of their own to use it. They survive only as parasites inside a living cell Outside of it, they are like any other nonliving matter Crystals of a virus can be stored in a bottle for several years When a virus infects a host cell, the machinery and materials of the host are diverted to obey the 'blue print' of the virus for reproduction Viruses cannot be cultured in an artificial medium without a living cell

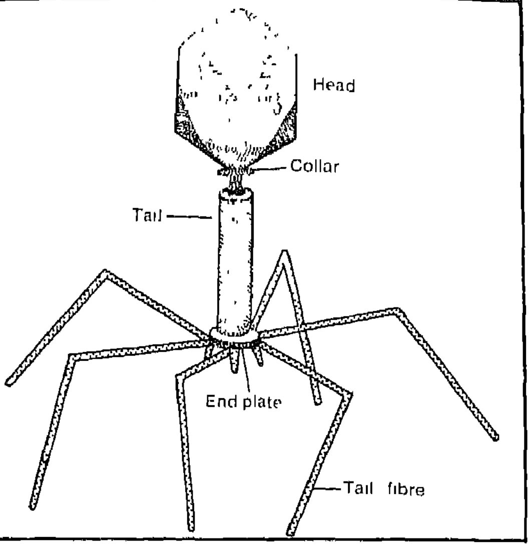
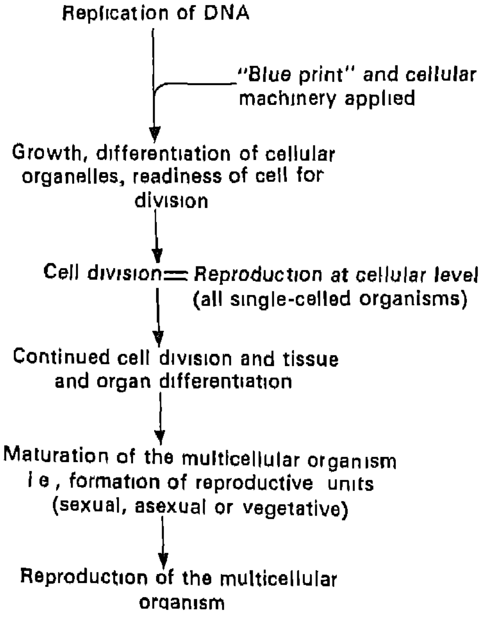


Fig. 2.6 T_4-phase bacterial virus

Reproduction in nature may be summed up as:


Replication of DNA
"Blue print" and cellular machinery applied
Growth, differentiation of cellular organelles, readiness of cell for division
Cell division = Reproduction at cellular level (all single-celled organisms)
Continued cell division and tissue and organ differentiation
Maturation of the multicellular organism i e, formation of reproductive units (sexual, asexual or vegetative)
Reproduction of the multicellular organism

You will read about asexual, sexual and vegetative reproduction in later chapters

Adaptation

Every organism has an inherent capacity to change You will read about the heritable changes or 'genetic variations' and their causes in later chapters Useful changes which help an organism to live well and successfully in its environment, are passed on generation after generation This helps a species to adapt itself to the environment If useful variations fail to appear, the ability to cope with the pressures of changes in the environment is diminished and so survival of the species becomes difficult. In such a case the species dies out and becomes extinct

Adaptations may be studied under two categories—short-term adaptations and long-term adaptations, perpetuated through generations Some familiar examples of these are given below·

Short-term adaptations

(i) Our skin when exposed to excess sunlight becomes dark (tanned) This is an adaptive response in which skin pigments (melanin) accumulate in the top layers of the skin, absorb excess radiation and protect the underlying tissues

(ii) Hibernating animals suspend all activities and maintain a very low metabolic rate until favourable conditions of the environment return. The energy for life processes is derived from stored fat.

(iii) Plants show adaptive responses such as photoropism (growth movement of a shoot towards light) and geotropism (growth movement of a root towards gravity) (Fig 2.7)

(iv) Dormant seeds suspend all their activities, so much so, that they appear dead Dormancy is broken and the embryó germinates when favourable conditions become available

Even these short-term adaptations are important for the survival of organisms

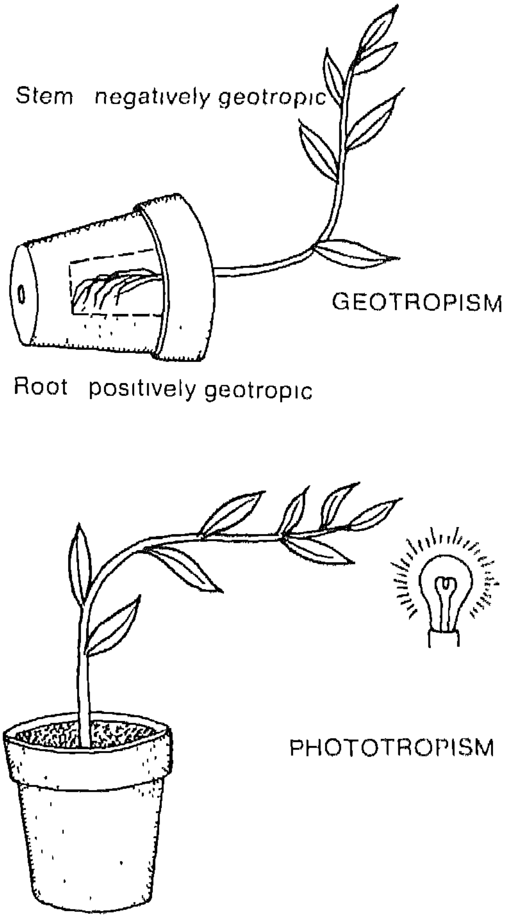


Fig 2.7 Phototropism and geotropism are growth movements in plants

Plants and animals differ in their response to stresses. Animals are able to escape stresses by moving away from them. Their responses are rapid and easy to observe As plants cannot move, their slow physiological responses are the principal means of adaptation Development of bark, scales around young buds and defoliation (leaf fall) help plants to bear severe cold However, you must remember that many conifers (gymnosperms) and a few angiosperms are evergreen and do not shed all their leaves at the same time In northern latitudes, there is such a synchronous and programmed dropping of leaves in early October, that the season is called the fall. Prior to the fall (abscission), leaves change their colour from green to yellow or red. It is indeed a dramatic and picturesque sight to see entire forests turning these colours This event is triggered by plant hormones in response to the signals they receive from shortening of day length and the reduction in night temperature.

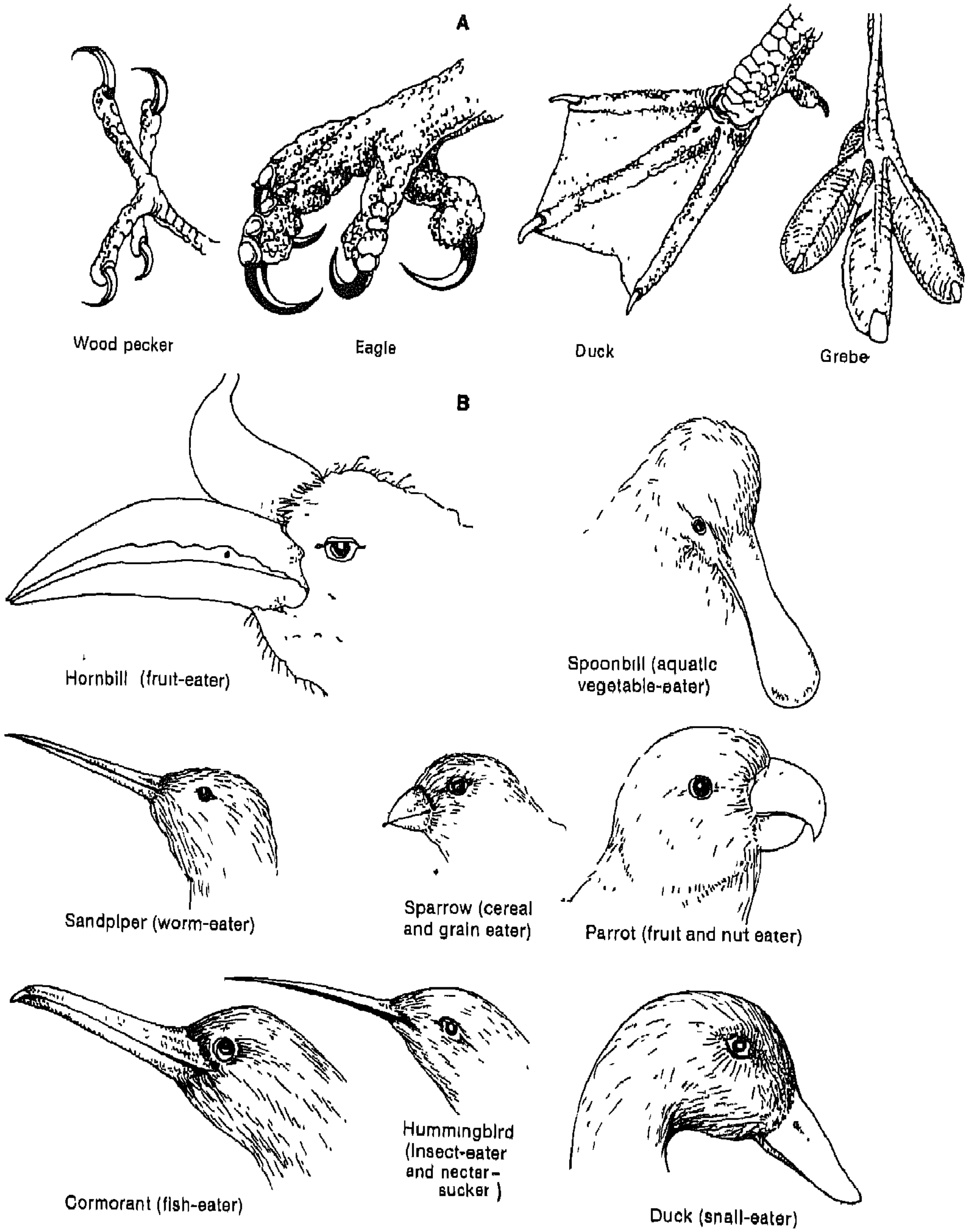

A
Wood pecker
Eagle
Duck
Grebe
B
Hornbill (fruit-eater)
Spoonbill (aquatic vegetable-eater)
Sandpiper (worm-eater)
Sparrow (cereal and grain eater)
Parrot (fruit and nut eater)
Cormorant (fish-eater)
Hummingbird (Insect-eater and necter-sucker)
Duck (snail-eater)

Fig. 2.8 A Types of claw structure in birds
B Forms of beak in birds

Long-term adaptations:

(i) Look at the claws and beak structures of the birds in Fig 2.8 These illustrate adaptations for specific perching and feeding habits.

(ii) The kangaroo uses its thick tail as a fifth limb (Fig. 2 9).

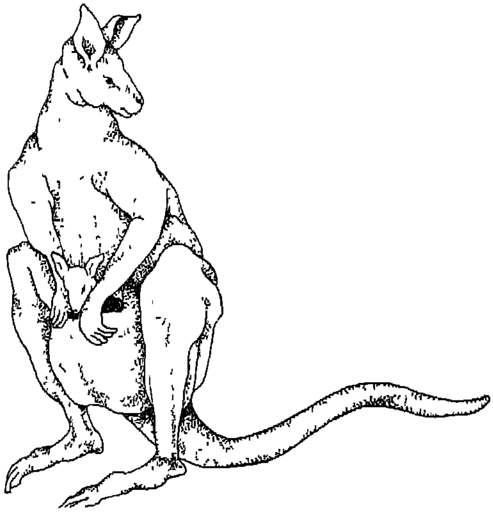


Fig. 2.9 The kangaroo uses its tail as a fifth limb

(iii) If our ankle bones did not protrude backwards, we could not have used our legs to stand erect (Fig. 2 10).

(iv) If thumbs were not opposable, our hands would not have developed the numerous skills such as use of tools, writing, spinning, weaving, etc. (Fig. 2.11).

(v) Plants growing in deserts are either leafless or have fleshy leaves and succulent stems covered by a thick epidermis and wax deposition

(vi) Night-blooming flowers are generally scented Many are white. These features aid in attracting pollinators

(vii) Protein of the mammalian blood is necessary for the production of mosquito eggs. Only female *Anopheles* mosquitoes have mouth parts suited for piercing the skin to suck blood. Male mosquitoes live on plant juices and lack blood-sucking mouth parts

These long-range adaptive features evolved gradually over hundreds of thousands of years Fossils show records of those organisms in the geologic past that could not adapt to changes in the environment and became extinct

In the vast diversity of living organisms, there are some fascinating instances of adaptation (Figs. 2.11, 2.12, 2 13 & 2 14).

These adaptations enable organisms to live in habitats through generations.

Do you know why a humming bird or a sun bird always hovers around but never sits on a flower? This is because many flowers are too small to support the weight of the tiny bird The bird is adapted to hover in flight, to sip nectar and capture insects hidden deep in the corolla. Honey bees and termites form complex, organised societies with adaptations for division of labour. How much organisations evolved is not clear.

Significance of Death

Death is an inherent part of an organism's life cycle Life spans vary greatly (Fig. 2.15). Although each species may live for a certain length of time, the biology of death is not completely understood. Among many animals the ageing, injured or otherwise useless individuals are often isolated and allowed to die. It is believed

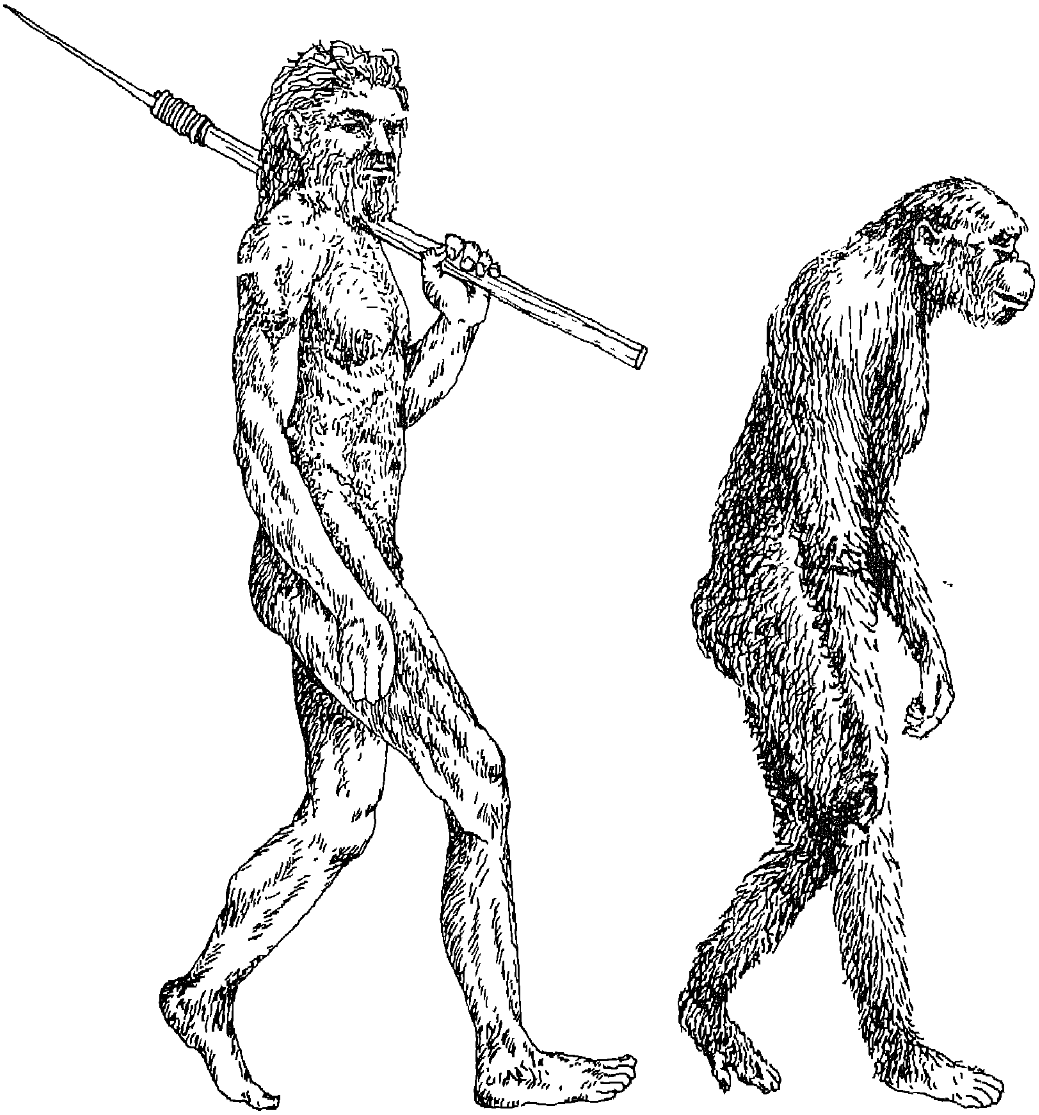


Fig. 2.10 Development of the erect posture: Ramapithecus, the earliest primate generally considered as ancestor of man. Ankle bone is not well developed. Cro-magnon man, the ancestor of modern man. Ankle bone is well developed.

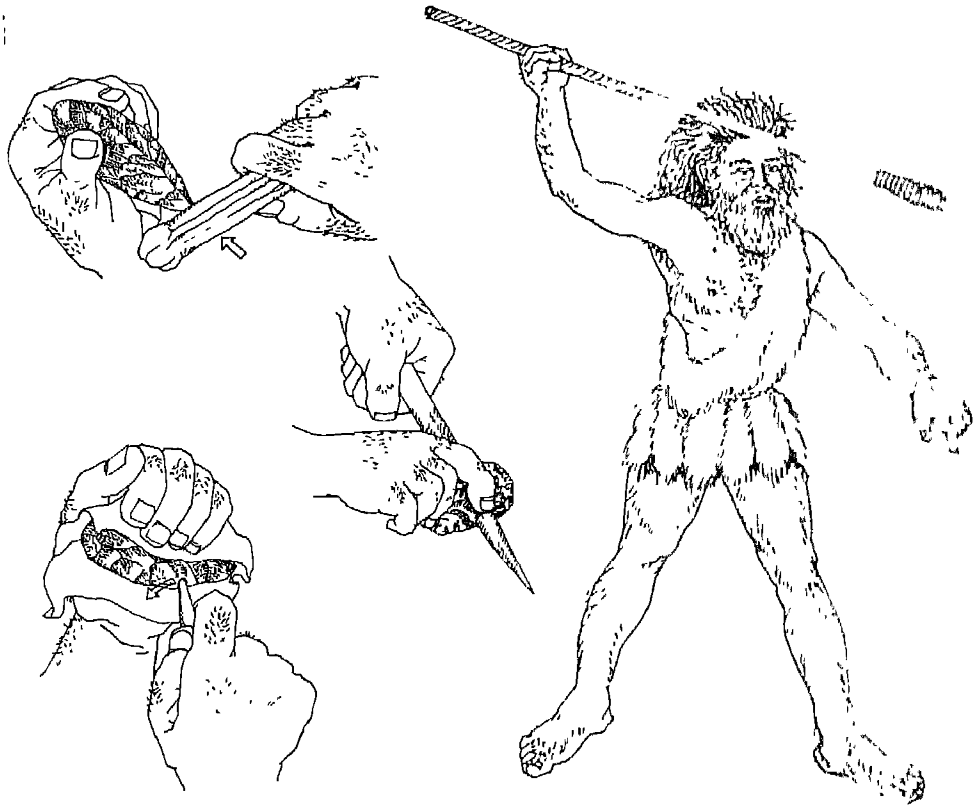


Fig 2.11 Use of opposable thumb by primitive man in tool-making

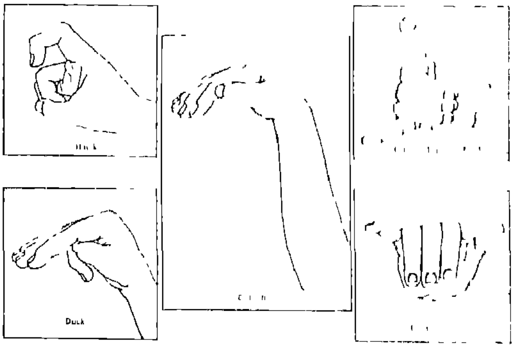


Fig 2 12 Fingers used in sign language by the bushmen tribe of Kalahari Desert in Africa During a hunt once an animal is sighted, the bushmen stalk in silence, using these signals to keep each other informed

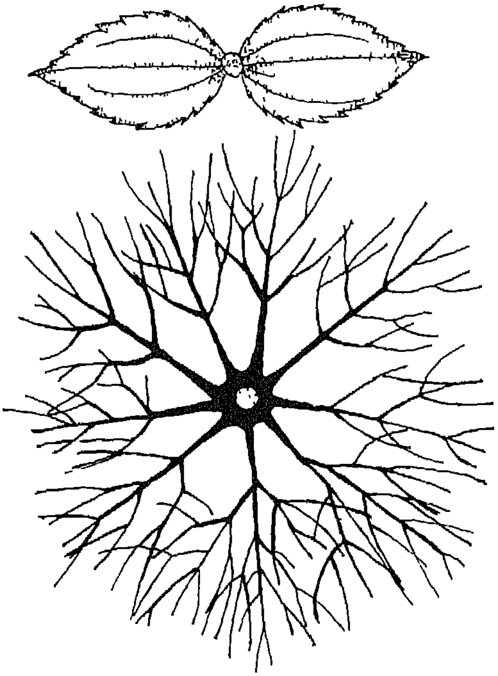


Fig. 2.14 Adaptation in the leaf structure of the aquatic plant *Limnophila*, under water leaf (below) and serial leaves (above) The finely dissected leaves are adapted to submerged conditions Both kinds of leaves are found on the same plant

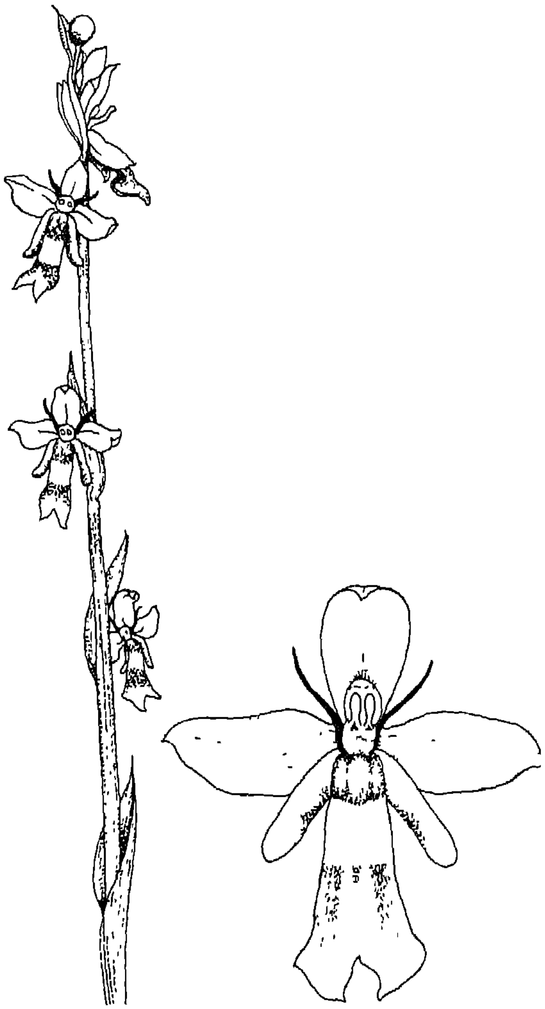


Fig. 2.13 *Ophrys muscifera* a member of the orchid family with flowers resembling the females of a certain species of wasp

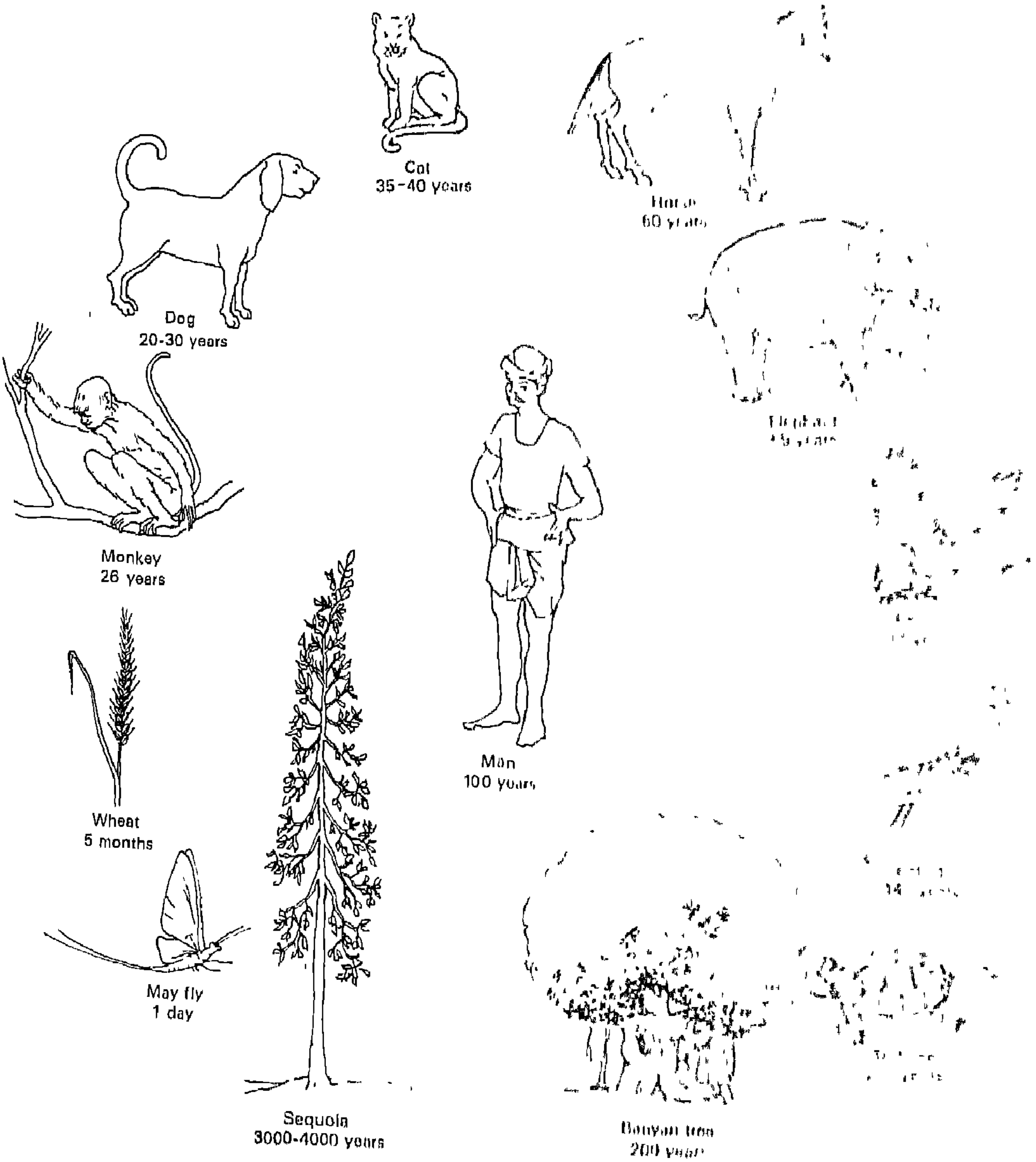


Fig. 2 15 The longest time over which the life of some common plants and animals may extend (life span)

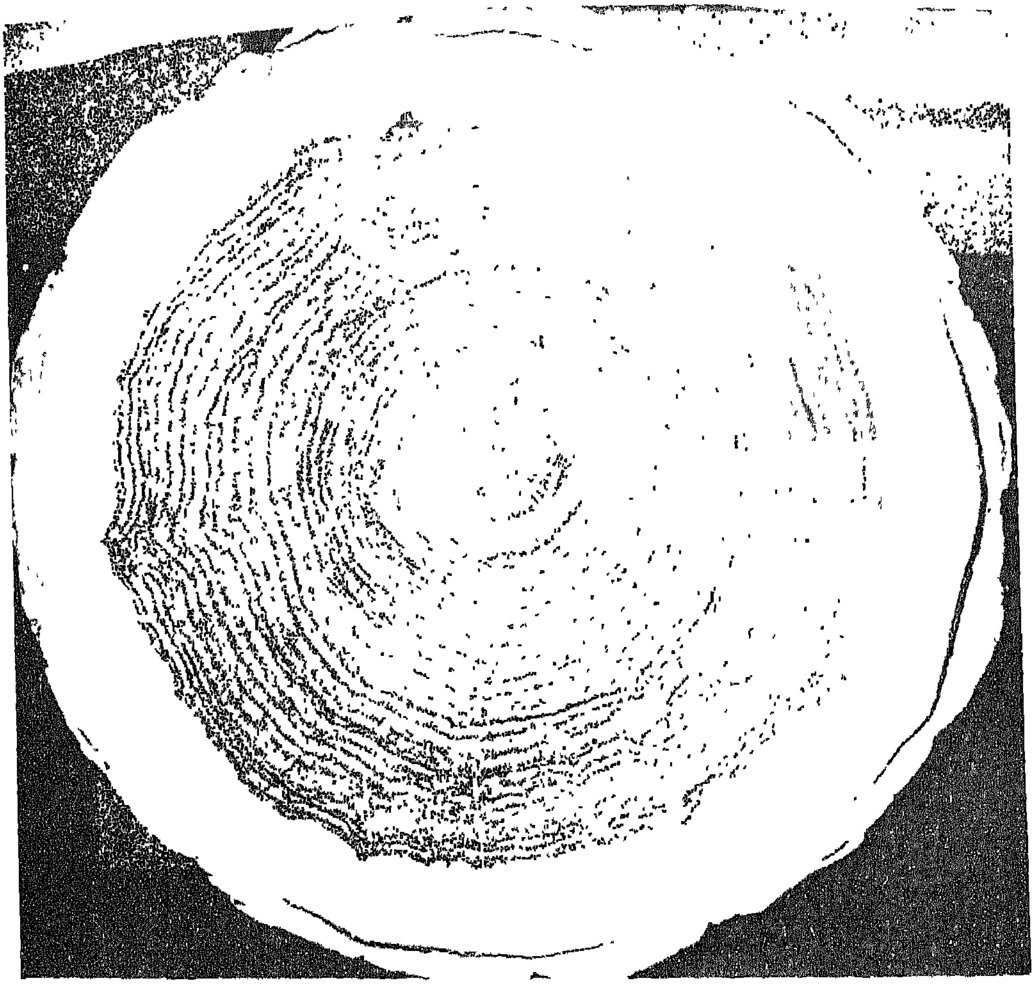


Fig. 2.16 Trunk of *Dalbergia sissoo* showing central heartwood (dark region with numerous rings) and peripheral sap wood (lighter region)

that some animals can sense that death is approaching. One wonders how long perennial plants can live. Some trees such as the *Sequoia* live for thousands of years This is partly explained by the fact that plants keep growing at their tips even though a large part of their body may consist of dead tissues

If death did not occur, it would have been almost necessary to invent it. There are a large number of advantages in death. Consider the following.

(i) The survival of a population depends on regulatory mechanisms that keep in check the number of individuals in a popula-

- Some species of small club moss such as *Selaginella lepidophylla* grow on exposed rocks with the ability to survive dessication. When placed in water they revive and are hence called 'resurrection plants.' *Myrothamnus* and *Craterostigma* grow in the highly arid regions of South Africa. Dark brown, dried-up plants when they receive a shower of rain, regenerate and revive. Their foliage becomes green and functional within a few hours of absorption of water. These plants are adapted to extreme dessication and appear 'dead' but come to life as soon as water is available.
- An amoeba divides into two cells, which in turn divide into two each and so on. When does an amoeba die? Bacteria divide every 15 to 20 minutes, the original losing its identity. When there is overcrowding, bacterial cells die as a result of their own toxic secretions. Can we call this natural death?
- Ciliates, hitherto thought to be 'immortal' due to their capacity for binary fission (asexual reproduction where a cell divides into two), are now found to age and die, after a certain number of fissions.
- A human being is clinically dead when there is no pulse (no heart beat) and his pupils are fixed and dilated (no reaction to light). Clinical death is not the same as biological death. Almost all the body cells remain alive for several hours after clinical death. This is why tissues and organs to be used for transplantation are removed within a few minutes after death.

tion. Death and reproduction contribute to this homeostasis. Imagine the consequences of overcrowding if organisms did not die.

(ii) When organisms die, they are decomposed by microbes. Elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur are freed from their bound form, and returned to the soil, air or water (material cycles). This is an important event that maintains balance in nature.

(iii) Dead cells or their derivatives serve important roles directly related to a living process.

(a) Dead tissues such as heartwood and cork in plants and nails, horns, hooves and down feathers in animals help in support and protection. The covering layer of our own skin is made up of dead cells and protects the body from loss of body fluids and from the invasion of harmful microbes.

(b) Mature sclerenchyma cells in a plant lose their contents and acquire thick walls. They provide mechanical support. Heartwood which is formed in the central portion of a tree, provides a strong internal support to the trunk so that it does not get uprooted.

Vessels in sapwood are dead but serve as channels for conducting water and minerals to great heights without leakage (Fig 2 16)

(c) During development of an organism some embryonic cells are programmed to die according to a time schedule During maturation of xylem in flowering plants, cross walls must dissolve in time to form long vessels Cells of the tail and external gills of a tadpole also die on schedule to help the tadpole become a frog

Barring accidents, ageing is a prerequisite for natural death in most organisms Many scientists believe that ageing and death are 'built-in' parts of the life cycle During ageing prevention of entropy by free energy is no longer possible and an organism ceases to exist. What are the factors that cause the organism to age and give up living? We do not have satisfactory answers to this question but the investigation continues

An Attempt to Define Life

Now that we are better acquainted with features that characterise the living than when we began this chapter, let us ask once again 'what is life?' We can at best make a few generalisations on living beings, if not on life

(i) An organism is a living machine.

(ii) It obtains simple molecules from outside, converts them into complex molecules, increases in size and complexity, reproduces itself to perpetuate its kind As an individual, it dies after an approximately predictable life span or by accident

(iii) A living system exhibits homeostasis.

(iv) It recognises internal and external stimuli and responds to changes in the environment and adapts itself.

(v) A living system shows, though not obviously, the ability to evolve in time

Putting it even more briefly, we may state· Life is a unique, complex organisation of molecules, expressing itself through chemical reactions which lead to growth, development, responsiveness, adaptation and reproduction.

SUMMARY

The living and the nonliving are made up of the same elements and are subject to the same physical laws. How, then, are the living different? The living have levels of organisation that are different and unique. Aggregation, interaction, equilibrium and change which regulate all types of organisation are more complex in the living. Life cannot be created by just putting together all the required elements in the right proportion with the required amounts of energy. An organism is not only an independent entity, it is part of the natural world.

Life has a molecular basis. It is predominantly organic in nature. Both micro and macro molecules are important for life. Macromolecules offer a large variety and participate in a wide range of chemical reactions. The two broad categories of chemical reactions are catabolism and anabolism.

Energy transfers and transformations continuously occur in a living cell. Chemical reactions of life are possible through such energy changes. ATP is the energy currency of a cell. Living systems are also subject to entropy. Organisms minimise entropy by deriving free energy from their environment. An organism has access to environment for matter and energy and is, therefore, regarded as an open system. An open system is also a system in a steady state, as the input of energy and matter are balanced by the output of energy and matter.

The living steady state is self-regulatory or homeostatic, i.e. organisms have the capacity to maintain their internal well-being, or physiological equilibrium in spite of changes in the environment.

Hormones are a good example to illustrate that most homeostatic mechanisms operate through a feedback system. Homeostatic mechanisms operate at all levels of the living hierarchy, and contribute to balance in nature.

Reproduction is a characteristic feature of all living organisms. It ensures the perpetuation of the species. DNA is the storehouse of all cellular information and is also the only molecule endowed with the capacity to replicate itself.

The inherent capacity of a living organism to change, gives it the potential to adapt and survive. Short-term adaptations help the organism in its survival. Long-term adaptations are significant in the evolution of the species.

Organisms show much variation in their life span. Death is an inherent part of the life cycle. The biology of death is not completely understood, but death plays many positive roles. Populations survive because overcrowding is countered by death. Microbial decomposition of the dead organisms is essential for the release and recycling of materials. Even in living plants and animals, dead tissues have specific roles.

We have learnt much about being alive. Yet it is problematic to give a satisfactory definition of life. It may be stated that 'life is a unique, complex organisation of molecules, expressing itself through chemical reactions which lead to growth, development, responsiveness, adaptation and reproduction."

QUESTIONS

1 What would be the consequences if
   (a) Organisms failed to reproduce?
   (b) Organisms were immortal?
   (c) Nails, horns and feathers consisted of living cells?
   (d) All molecules in the cell were identical?

2. Which of the following explanations accounts for the statement -
   "It has yet not been possible to create life."
   (a) The nature of molecular organisation is complex and not completely understood
   (b) All molecules of life have not been identified yet
   (c)Most molecules are known, except for a few

3 You have observed that organisms die Which of the following statements appear to you scientifically sound?
   (a) An organism dies because all its cells die
   (b) Because organisms can be born again
   (c) Death is a natural part of the life cycle
   (d) Otherwise the earth would become too crowded.

4 Arrange the following in ascending order without referring to your text
   population, atoms, individual, molecules, biosphere, community, cells ecosystem, tissues and organs

5. Explain why there is greater emphasis on a molecular approach to understand life today than before?

6 Listed below are certain situations
   (a) A wheat crop is ripening in a field
   (b) Ram is participating in a long-distance running competition
   (c) You burnt your hand, but it has recently healed
   (d) Sita is fast asleep
   Explain these in terms of energy transfers and or transformations.

7 What does 'entropy' mean? How does a living organism cope with entropy?

8 Compare the working of an automobile with that of your body. Which features are common, and which different?

9. How is it that 'being alive' means the same to an amoeba, a mango tree, a butterfly or a human being?

10 By suitable examples, explain the terms 'steady state' and 'homeostasis.'

CHAPTER 3

LIFE, ITS ORIGIN, EVOLUTION AND MAINTENANCE

LIFE originated on earth millions of years ago and a wide range of living being has evolved since then What are the mechanisms by which the diversity of life has been maintained in nature for so long? Human beings are the most recent and the most highly evolved among organisms. What is their place in the universe and role on this planet? In this chapter we shall study some aspects related to these questions

Origin of Life

Is earth the only planet where life could originate and evolve? Or did life begin in some other planet and then come to earth? It is difficult to imagine that any particle of life could travel through a vast expanse of space amidst hazards of radiation and high temperatures and reach our planet Yet, some scientists have suggested the possibility Other parts of the universe originated under identical conditions as planet earth and probably had the same kind of primitive matter It is thus almost unbelievable that the same elements that make up the universe were able to create life on one planet and leave the others without a trace of life In our solar system, Mars has provided evidence of the possibility of life. Scientists are continuing to explore life in outer space

We have learnt what it means to be alive, but we are not clear about how life came to be. No one has seen it happen We only have fragments of evidence which have helped scientists to trace the possible events of the past, up to 3000-4000 million years, the approximate time when life originated. Thus the story of the origin of life is based on 'this is what may have happened '

The origin of the earth dates back to 4,500 million years The earth which was still in the process of developing had a reduced atmosphere. It is thought that nitrogen, hydrogen, ammonia, methane, carbon monoxide and water were present. Energy was available in the form of ultraviolet rays and electrical discharges (lightening). As the crust of the earth was being formed, torrential rains poured over the earth for centuries forming large masses

THE BIG BANG, SOLAR SYSTEM, ORIGIN OF EARTH

Scientists believe that 10,000–20,000 million years ago the universe consisted of a single piece of concentrated matter. The matter exploded (Big Bang) throwing out hydrogen atoms and related nuclei which became organised into galaxies

Cosmologists have estimated that the universe has approximately 100,000 million galaxies All the galaxies appear to be moving away from one another at great speeds, approaching the speed of light. In each galaxy, stars are born and die continually. Our galaxy, the milky way, is just one of them All the stars that we can see with the naked eye belong to our galaxy. Our sun is one such star, and along with the orbiting planets and their satellites, the comets and asteroids, constitutes our solar system. Earth is a part of the solar system. Our sun is not the only star to have planets, but the other stars are too distant to be seen even with the largest and most powerful telescopes

How did our solar system originate? Scientists have different answers to this question The prevalent view is that the solar system originated by the gravitational contraction (condensation) of a cold cosmic cloud of dust and gas called nebula. During condensation, this cloud began to rotate due to the initial velocities of the particles brought together. As condensation and spin continued, most of the mass concentrated near the centre and the flattened disc broke into a number of whirling masses of smaller clouds The sun was formed from the dense centre. Condensation caused the temperature to increase and when the temperature was high enough, nuclear reactions started and the new star "sun" began to radiate energy The planets, including the earth, were formed from the cooler, less dense outer regions, almost in the same plane Condensation occurred in each of these smaller clouds, concentrating the heavier elements at the centre.

of water The atmospheric compounds and inorganic salts and minerals gradually dissolved in the large water bodies to form oceans (Fig. 3.1). The oceans were like a 'broth' and gave rise to a variety of compounds and finally to the self-duplicating molecules (Fig. 3.2).

The self-duplicating molecules ultimately became enclosed in membranes (derived from lipids and proteins) along with a pool of chemical compounds including water to form the first 'cell-like' structures. There are many gaps in our understanding of how exactly the first metabolising and self-replicating cell came into existence We know today that proteins cannot be synthesised without DNA and DNA cannot be made without enzymes, which are proteins. It is a kind of 'chicken-and-egg' situation.

The first organisms were anaerobes, as molecular oxygen was absent. They must have depended on the organic molecules present in the 'broth.' Such organisms are called CHEMOHETEROTROPHS The next organisms to appear were able to obtain energy by the degradation of chemical com-

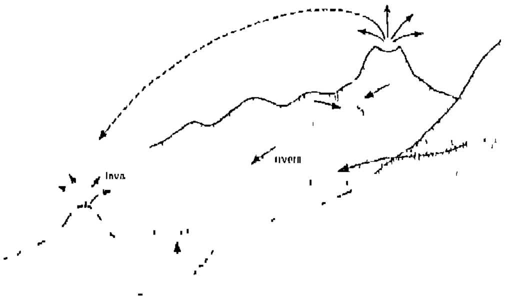


Fig. 3 1 Source of ocean salt Some came from volcanoes; some was dissolved out at the sea bottom, some resulted from tidal action, which crumbled and dissolved the shorelines Some originated on land leached by rain and rivers

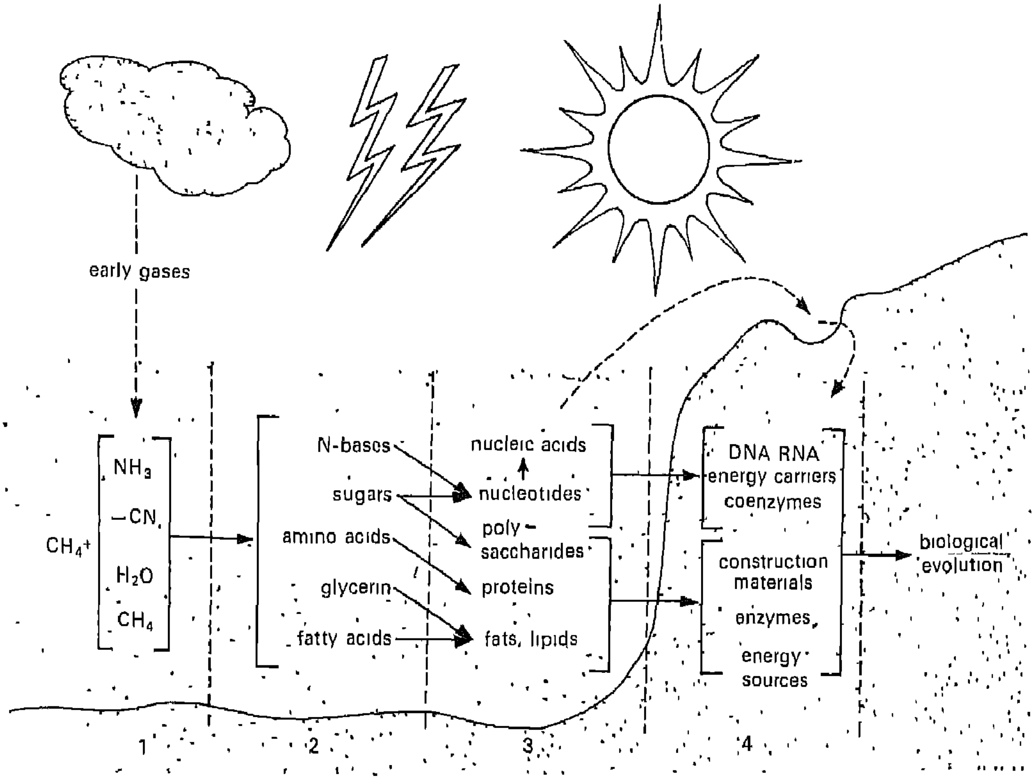


Fig 3.2 Chemical evolution is believed to have occurred in at least three or four successive phases The original gaseous raw materials came from the early atmosphere (1) and with the aid of energy from lightning and ultraviolet light, key biological compounds were synthesised progressively in the ocean (2, 3) Then, later, more complex synthetic reactions occurred along the shore, where required ingredients became highly concentrated by the evaporation of water (4) The outcome was the origin of the first living units

pounds for the synthesis of food molecules (*anaerobic chemoautotrophs* such as sulphate reducing bacteria)

Evolution of the chlorophyll molecule may have been a landmark in the sequence of processes related to early diversification of life Cells containing chlorophyll were able to utilise light energy to synthesise carbohydrates The first *photoautotrophic* bacteria were anaerobic and did not also produce oxygen because they did not use water as a reagent. There is a recent finding that the aerobic photoautotrophs (cyanobacterium-like, oxygen-producing photosynthesisers) originated 3300 to 3500 million years ago

These organisms released oxygen as a free gas Oxygen became a new means of releasing energy by respiration, and autotrophs became a source of food, for the heterotrophs In this manner photosynthesis and respiration became estabished at a very early stage as nature's prime balancing mechanisms (Fig 3.4)

Filamentous and colonial fossils of these microorganisms have been discovered in western Australia Scientists of the Birbal Sahni Institute of Palaeobotany, Lucknow, have discovered such cyanobacteria from India which are 2900 million years old (Fig. 3 3)

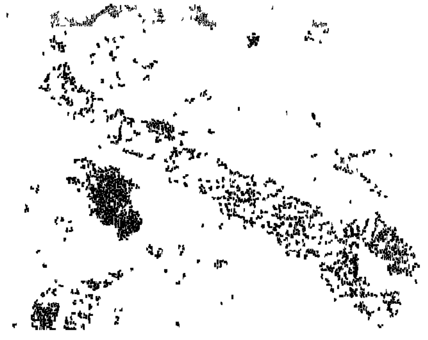


Fig. 3.3 Early photosynthetic oxygen producing cyanobacteria found as a fossil and believed to be 2 9 billion years old (Courtesy Dr B S Venkatachala, Birbal Sahni Institute of Palaeobotany, Lucknow)

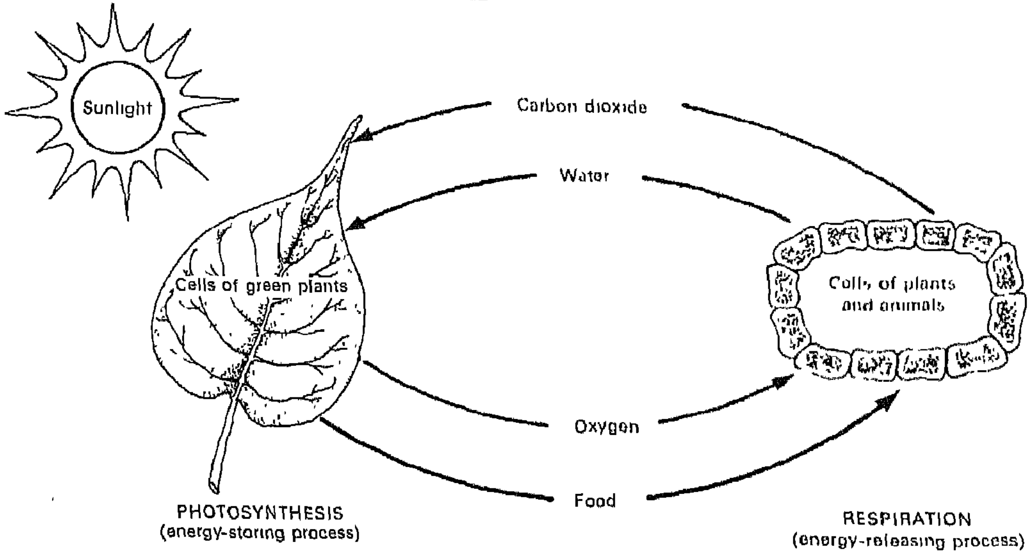

Sunlight
Carbon dioxide
Water
Cells of green plants
Cells of plants and animals
Oxygen
Food
PHOTOSYNTHESIS (energy-storing process)
RESPIRATION (energy-releasing process)

Fig. 3.4 Photosynthesis and respiration balance each other.

The emergence of photosynthesis had a tremendous impact not just on evolution and the development of organisms, but also on the whole history of planet earth Photosynthesis changed the earth's atmosphere from a reducing to an oxidising one Until this change occurred the environment to support life as we know it today could not have come into existence

APPROXIMATE ORIGINS IN MILLION YEARS

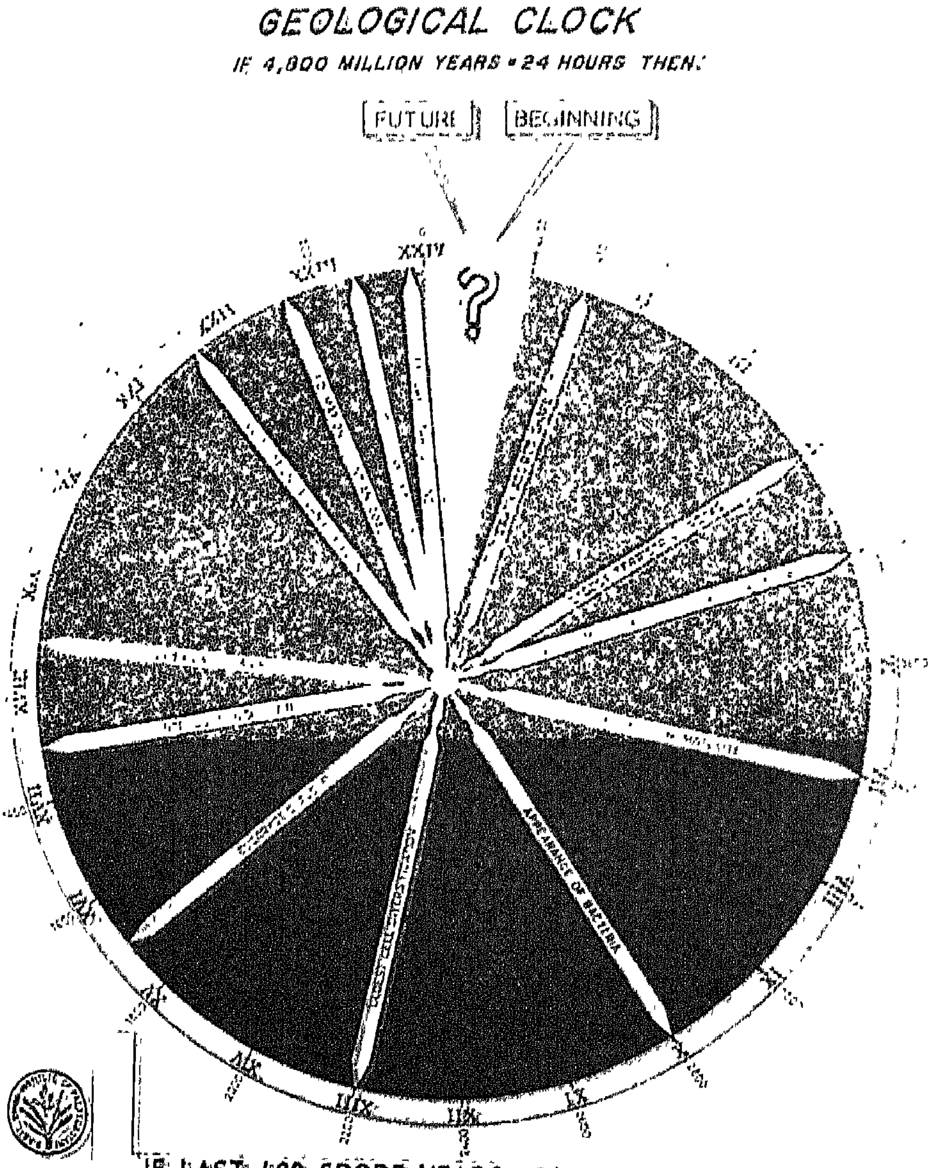
Universe	10,000-20,000
Solar system	4,600
Earth	4,500
Abiotic chemical evolution; anaerobic life	4,200
Beginning of traces of oxygen	3,800
Anaerobic photosynthetic bacteria	3,500-3,800
Oxygen producing photosynthetic cyanobacteria	3,300-3,500
Eucaryotes with a nucleus	1,600
Simple land plants	459
First mammals	220

You have studied that life originated in water Water continues to be an essential requirement of life If liquid water is available on other planets, life could be expected to originate there too It is almost impossible to think of any other molecule that could have replaced water A few properties of water that make it unique in sustaining life are

- Water is a liquid between 4°-90°C, and life exists approximately at this range of temperature
- Water is a stable compound and does not decompose easily Hence it forms a suitable medium for chemical reaction.
- Water protects organisms from thermal shock Whether organisms are in water or water is inside them, it does not allow quick changes of temperature This is due to its properties of latent heat
- Water expands on freezing, becomes lighter and floats as a sheet of ice Floating ice keeps the water underneath from freezing and protects aquatic plants and animals If ice were to sink, the seas of the colder regions would have solidified from bottom upwards, and all life in them would have been exterminated But the antarctic sheet of ice has abundant flora and fauna below it
- Water is a source of molecular oxygen and hydrogen ions in living cells
- Water is an excellent solvent, probably there is no other solvent in nature that is superior to water
- Dry chemicals that are non-reactive becomes reactive in the presence of water.
- Water is a splitter and a binder (Recall the hydrolytic reaction and polymer formation by dehydration synthesis that you studied in Chapter 2)

Evolution

Evolution is a naturally occurring process. There is evidence that every kind of living organism has the potential to evolve, Evolution is a slow, continuous and irreversible process of change Complex forms of life have emerged from simpler forms over millions of years Evolution occurs through variations arising from changes in genetic material and from natural selection, about which you will study later All living organisms have arisen through the evolutio-



IF LAST 480 CRORE YEARS = 24 hours THEN

EARTH AQUIRES SHAPE AT	0 30 hours	INTRODUCTION OF DEATH AT	17.30 hours
OLDEST TERRESTRIAL ROCKS FORMED AT	04.00 hours	APPEARANCE OF ANIMALS AT	18.30 hours
OLDEST SEDIMENTARY ROCKS FORMED AT	05.00 hours	COLONISATION OF LAND BY PLANTS AT	21.40 hours
FIRST APPEARANCE OF LIFE AT	05.00 hours	FORMATION OF INDIAN COAL AT	22.45 hours
[illegible]	10.00 hours	FLOWERING PLANTS APPEARED AT	23.25 hours
[illegible]	13.00 hours	RISE OF HIMALAYA AT	23.53 hours
FIRST [illegible] ALGAE AT	15.30 hours	MAN APPEARS AT	23.59.30 hours

Fig. 3.5

nary process and show diversity Yet a fundamental similarity exists among them

All living beings are made up of nearly the same elements and have cells as their structural units They obtain energy from their environment and synthesise the building blocks of their macromolecules These processes are carried out by a well-integrated network of chemical reactions called metabolism 'Being alive' means the same to all organisms This is their unity Metabolism, replication and homeostasis are three characteristics of the living In spite of this basic unity, nature is full of diverse forms of life, ranging from bacteria to human beings and from diatoms to trees

EXAMPLES OF EXTREME VARIATIONS OF SIZE

1 The world's tallest tree is *Eucalyptus regnans* Its recorded height is 114 m(375 ft.) The Californian coast redwood (*Sequoia sempervirens*) is 111 m tall (366 ft)
2 The largest animal that has ever existed upon the earth as far as we know is the blue or sulphur-bottomed whale which reaches a length of 30 m.
3. In a plant named *Amorphophallus* in Sumatra, the inflorescence (flower-bearing axis) grows to a height of 5 5 m.
4 The smallest and the simplest of the flowering plants resembling small dots or grains floating on still water is *Wolffia arrhiza*
5 *Rafflesia* has the world's largest flower, one metre in diameter with 2.5 cm thick petals. It is a parasite and lacks true stem or leaves
6. *Acetabularia* is a single-celled alga and measures between 6 and 10 cm

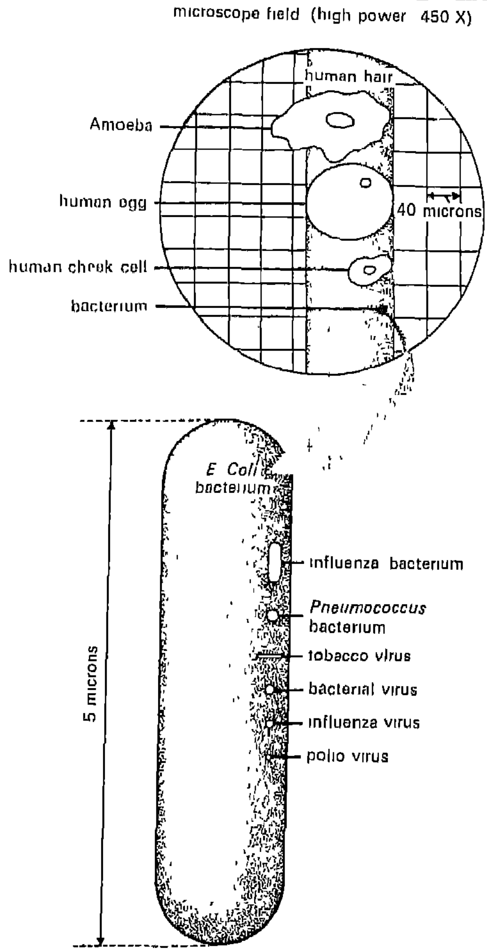


Fig 3 6 Variation among the small The size of *E coli* bacterium is compared with the other cells and structures

SOME EXAMPLES OF DIVERSITY IN MODES OF LIFE AND BEHAVIOURAL RESPONSES OF LIVING ORGANISMS

1. Cicada—an insect with a life-span of seventeen years sleeps most of the time It emerges from the ground, is awake for about five weeks and then dies.
2. Dolphins can imitate human speech and even laughter
3. Some Indian bats can detect insects, the size of the thickness of human hair (0 08 mm). They can consume insects weighing nearly twice their own body weight per day
4. Some spiders build a bell-shaped home entirely under water.
5. The male *baya* or the weaver bird of India builds an elaborate nest, using strips of leaves of sedges and grasses. The female inspects the nests and selects only that male who is a fine builder. To attract the female, the male often decorates the nest with colourful petals.

Organisms not only exhibit diversities with respect to one another but also an enormous multiformity within themselves. The life processes in the human body are a good example to illustrate this

Evolutionary evidences also reveal that there is complementarity of structure and function Consider the following examples

- Birds and insects do not share a common ancestor but both have wings, as both fly
- Insects and plants are totally different from each other Yet a remarkable similarity is shown in their cuticle which serves as a hard protective cover
- Insects such as the cockroach have biting and chewing mouth parts, whereas a mosquito has piercing and sucking mouth parts These organs are suitably adapted to specific feeding habits
- Total animal parasites such as the tapeworm do not have elaborate organ systems, although their free-living ancestors possessed them

Now you can understand how diverse organisms may have similar functions, and closely related organisms may show great differences.

The Living Crust of the Earth and its Maintenance

Life does not exist everywhere on the earth It is mainly the crust of the earth that is habitable The habitable regions of the earth lie within an amazingly thin layer of about 22 5 km, from the highest mountains to the deepest oceans The solid part of the

SOME INTERESTING FACTS ABOUT THE HUMAN BODY'S STRUCTURE AND FUNCTION

- The fastest nerve impulse travels at 532 kph.
- The adult human lungs have an internal area of 93 m^2, which is 40 times the external surface of the human body
- Human beings have more body hair than apes, but of a shorter and softer variety.
- There are about 96,000 km of blood vessels in our body
- We spend 30 minutes every day being blind, the time taken by blinking.
- Bones are as strong as concrete and as hard as granite, but far lighter than both

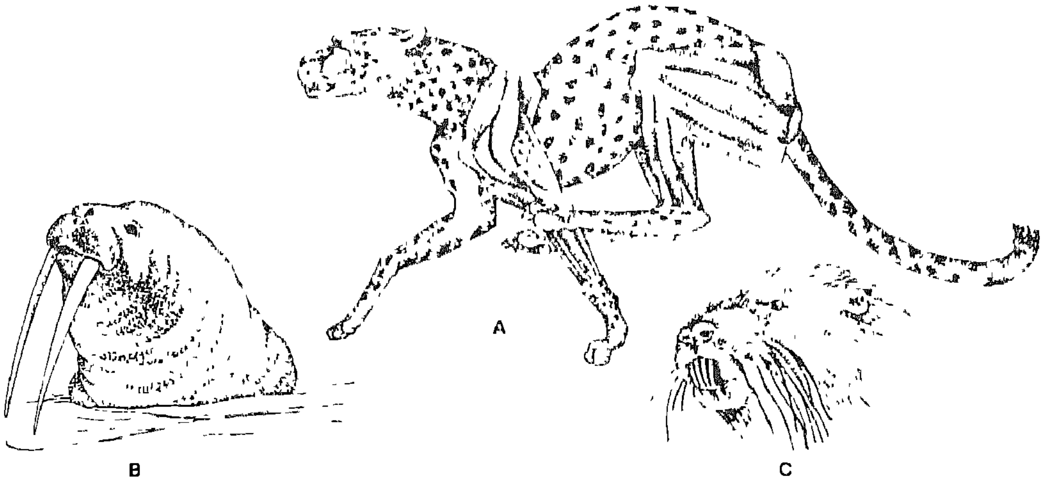


Fig 3.7 Structure-function complementarity A The cheetah bounds forward pushed by its powerful hind legs It is the fastest land animal. B The walrus digs with its long ivory tusks. C The rodent has gnawing incisor teeth

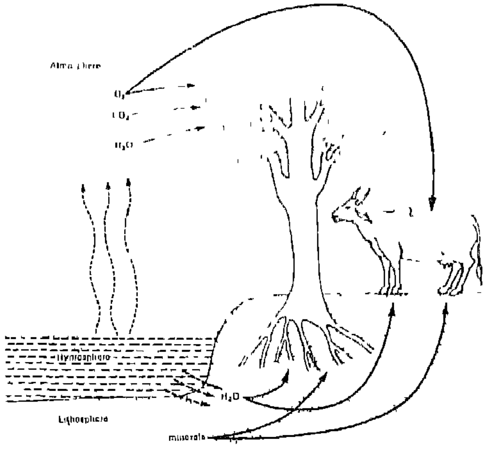


Fig. 3.8 The living crust Atmosphere, Hydrosphere and Lithosphere

earth is called the lithosphere; the water part is termed the hydrosphere. These, together with the air of the atmosphere, constitute the biosphere or the livable part of earth (Fig , 3.8). In the biosphere the density of life is highly varied. The distribution of life depends on numerous factors. Tropical rain forests have a high density of organisms Deserts and snow-capped mountains have a sparse distribution of organisms Little life is possible inside live volcanoes or extremely hot springs

The physical and chemical characteristics of the three major domains interact and influence life in many ways. Random changes keep occurring in the contours of the earth These are rather slow but have influenced life forms. Changes like degradation (wear and tear), aggregation (building processes), diastrophism (movement of solid parts with respect to one another) result in folding, raising or lowering of land masses. Thus we know that many parts of the present land masses were once under the sea, and what is submerged in the oceans today may emerge as land masses in the future. These geographical changes have been closely related with changes in living forms also. This is evident from the study of fossils obtained from different strata of earth and belonging to different geological time periods

THE TALLEST MOUNTAIN TODAY WAS ONCE BURIED UNDER A SEA

Mt. Everest,, the highest mountain peak on earth, consisting mostly of limestone, formed a part of the Tethys sea, some 240 million years ago. This was uplifted due to the collision of the Indian plate with the central Asian plate.

Organisms cannot exist in isolation. You have learned in Chapter 1 that the branch of biology that explains the relationship of a living organism to its environment, living (biotic) and non-living (abiotic), is called ecology A major concern of ecology is the study of ecosystems

Ecosystems may vary in size from a drop of water from a pond to an ocean, from a patch of grassland to a forest Any place, however small, can be an ecosystem, as long as living organisms are in it (Fig. 3 9).

Maintenance of ecosystems depends upon specific types of interdependence. These are the material cycles, food chains and webs, and energy flow. Material cycles involve utilisation of elements and compounds in nature such as water, oxygen, nitrogen, phosphorus, carbon dioxide and their return to the environment Photosynthesis and respiration are the two life processes that maintain a balance of carbon dioxide and oxygen in nature. Bacterial decomposition of organic matter after the death of individuals, returns other kinds of material to the environment Material cycles also illustrate the environmental steady states

Nitrogen, which was once a part of a dinosaur, may have formed a part of a professor's brain, and at some time in the future may enter a cabbage that you will eat for dinner.

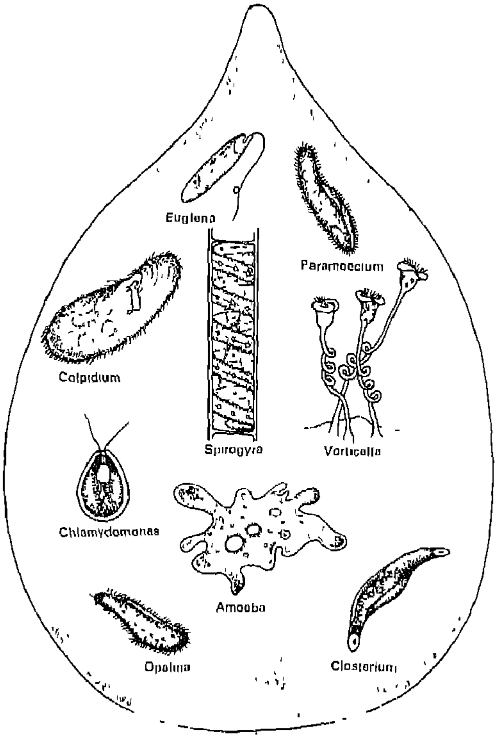


Fig. 3.9 Some forms of life in a drop of pond water

Food chains keep a check on population sizes through an 'eating-and-being eaten' kind of interdependence. Organisms are linked through their trophic levels. Most food chains form links with other food chains to establish a food web The sun is the ultimate source of energy. The flow of energy is unidirectional. Energy flows from the autotrophs to heterotrophs through food.

The whole environment is like one living organism with its homeostatic mechanisms operating all the time. We know that organelles of a cell, cells of a tissue, tissues of an organ and organ systems of an individual are all interdependent and coordinate to maintain homeostasis Similarly the entire environment with its biotic and abiotic components are interlinked in a complex manner to maintain a balance in nature. Just as new life cannot be created (so far this has not been possible, although the components of life-making machinery are known to man),an environment once destroyed cannot be recreated in its original form

Our Place and Our Role

The biological name given to us human being is *Homo sapiens* (*homo* = man, *sapiens* = wise, experts prefer to use *Homo sapiens sapiens*) The human being certainly is an animal, but an animal with unique characteristics At a biological level, the human being is not unique for strength, ability, speed or endurance Human beings also have a poorer sense of hearing, smell and vision than many other animals. Yet we are special because of the large and highly evolved brain and the skilled hands we possess. We are unique because we are tool-makers, we are not at the mercy of the environment and we can substantially alter the environment to suit our needs But what is the place of human beings in the universe? This knowledge is essential to have a better understanding about ourselves

The earth on which we live is a mere speck, in the whole system of things in the universe It is difficult to apply statistics to define our place in it Yet, this speck, the earth, is significantly large and important for us because we live on it and it is our responsibility to preserve it

Human dominance on this planet is a comparatively recent phenomenon. It probably got started when man,the hunter and gatherer, became a cultivator and herdsman The discovery that seeds are a source of replenishment of plants became the basis of agriculture Settlements along river valleys ideally suited to agriculture led to the establishment of civilisations.

OUR PLACE IN THE UNIVERSE

The vastness of the universe is mind-boggling

1 There are about 100,000 million galaxies like ours in the observable universe and on an average 10,000 million stars in each galaxy. Our galaxy is the milky way or 'Akashaganga'.
2 Our solar system revolves round the centre of the milky way galaxy once in every 237,000,000 years, at a speed of 792,000 km/hr.
3 The closest star (Alpha centauri) is 4.3 light years away (1 light year = 792,458 km/sec) and there are stars that are 800,000,000 light years away.
4. Our sun, 148·7 million km away, with a radius of 691·5 thousand km could hold more than a million earths, if it were hollow
5 The sun uses some 4,000,000 tons of hydrogen per second, which turns to helium, giving the sun its luminosity
6. It is this radiant energy which maintains life on earth. The sun has already lived half its life, and will probably exhaust the remaining energy in 10,000 million years
7. This is an ordinary sun, not the biggest or the smallest. It is neither the brightest nor the dullest.

We can probably trace this cultural evolution to the highly evolved human brain which contains approximately 10,000 million nerve cells Today, we can feel justifiably proud of the various achievements of human beings in space travel, electronics, atomic energy, lasers, genetic engineering, nuclear fusion and fission and so on. We alone can and have brought about major changes in all types of environment. Land has been reclaimed from the seas and put to use. We have built aircraft that can fly at supersonic speed and machines that can swim under the oceans. We have domesticated useful plants and animals and have secured their maximum productivity. Agriculture and horticulture are becoming increasingly mechanised.

Not satisfied with his own environment, the human being has entered the extra-terrestrial environment. 'Is there life in outer space?' has been his perennial quest. We anxiously wait to know whether life exists on Mars or Venus. Dogs, monkeys and apes made history by being the 'firsts' to orbit the earth in man-made space-crafts. Animals cannot explore space. Human entry into space was a must, for only he can observe, measure, record and analyse a wide range of physical phenomena through ingeniously devised instruments and test his own physiological and psychological changes at zero gravity.

Let us not forget that the human structure and function did not evolve in space and are not designed to support life in space.

What will happen to you (and also to the astronaut) when you start moving out into space, unprotected?

1. At 7.2 km, N_2 absorbed in blood is released as bubbles, because of a drop in pressure.
2. At 16 km — complete lack of O_2 in lungs.
3. Impact of great acceleration, organs get shocked, circulation and muscular movements are impaired.
4. Deafening noise produces nausea and choking.
5. Sun glare in empty space is blinding.
6. Very high temperature and radiation cause hazards to damage cellular controls.
7. Weightlessness and hazards of being a human being produce social, cultural and physical isolation and finally a detachment, dangerous for any emergency in space.
8. Change in the 'earth kind of biological clock' to a 'space kind of clock.' Will the human being have problems in getting back his 'earthly clock' after long exposure to space?

Discoveries in science have made life comfortable for some people, but each discovery brings with it some new problems. Let us look into some of these 'progress-linked problems'.

(a) Technology has given us more industries, and prospects for a better and more comfortable life. But it has also led to indiscriminate and unequal use of natural resources, industrial pollution and production of weapons of large-scale destruction.

(b) Effective crop protection practices have boosted crop yields. But thoughtless use of fertilisers and pesticides has destroyed the quality of land, water and air, besides affecting flora and fauna. New resistant forms of pests have emerged.

(c) Amniocentesis is a technique by which foetal cells can be made available to examine outside the mother's body. Chromosomal disorders, as well as the sex of the foetus, can be detected. But this technique has also led to the malpractice of termination of female foetuses by induced abortions.

(d) Genetic engineering is of great significance in agriculture and medicine. For example, cloning the human insulin and human growth hormone genes has become possible using bacteria Great advances in agriculture are expected in the near future. Yet, in experimenting with genetic transformation of organisms, there are remote chances of serious accidents and undesirable consequences if stringent precautions are not excercised. These advances can also be misused for biological warfare

(e) Surpassing all these is the problem of over population! The doubling time of human population has become reduced drastically (Fig 3 10) On the one hand, progress in application of medical sciences has resulted in the large-scale eradication of communicable diseases, reduced rate of infant mortality and has ensured healthy and long lives for human beings On the other hand, large masses of people continue to live in complete ignorance of the consequences of a population explosion While some countries have stabilised their population, the rate of increase in the developing countries is still alarmingly high. The root of every problem, whether related to the scarcity of food, clothing, shelter, education or employment, is the increasing global population

(f) So-called 'natural disasters' are taking a huge toll, in spite of scientifically correct predictions on earthquakes, floods and storms This is because these disasters are more 'created' than 'natural'. Vast areas of forestland and natural barriers to storms have been removed, making human settlements more prone to such hazards

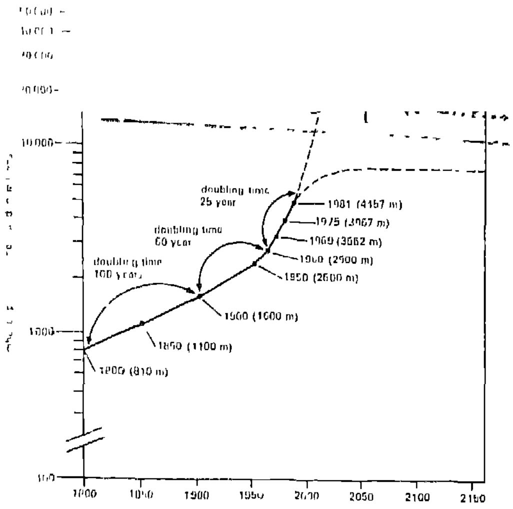


Fig 3 10 Explosion in global population

Time to Pause and Ponder

We can feel justifiably proud of the advances made in agriculture, medicine, biotechnology, energy and industry Yet we are confronted with problems of pollution, over-population, depletion of natural resources and extermination of wild life. There is little doubt that a major part of this crisis is due to our own obsession with self, greed, indifference, ignorance, shortsightedness and, above all, arrogance While we cannot stop making 'progress', it is amply clear that the kind of future we may create is a matter of our own choice (Fig 3 11)

We must realise that we need our environment for our own existence and to sustain all other forms of life We must regard nature with the respect it deserves as a source of a life-supporting system. Our understanding must help us to learn to adapt ourselves to nature's ecological laws, rather than disrupt its delicate balance and, in the process, destroy ourselves and the rich diversity of life.

Fig. 3.11 The human animal has come to dominate biological creation

SUMMARY

The story of the origin of life is built on speculation. It is not certain whether life originated on this planet or originated elsewhere and was transported here.

The history of the earth goes back 4,500 million years. It had a reducing atmosphere and the oceans were like a 'broth' with a large variety of minerals and salts dissolved in it. Chemical interactions led to the formation of a variety of complex molecues, including the self-duplicating DNA. These molecules, once enclosed in membranes alongwith a pool of other compounds, became the first 'cell-like structures.'

The first organisms were probably chemoheterotrophs which depended on organic molecules in the broth for obtaining energy. They were anaerobes. The next to evolve were the anaerobic chemoautotrophs which used chemical energy to synthesise food molecules. Evolution of chlorophyll molecule led to the evolution of photoautotrophic anaerobes. They did not produce oxygen to begin with, as water was not used as a raw material. Fossils of aerobic, oxygen-evolving photoautotrophs have been recently discovered and date back 3300-3500 million years. With the release of oxygen from photosynthesis, respiration and photosynthesis became established as important balancing mechanisms of nature.

Life must have arisen in water. Some of its unique properties are as follows: it is a liquid within a suitable range of temperature, is an excellent solvent, protects life from thermal shocks, accelerates chemical reactions and is a splitter and binder of molecules.

The origin of life was followed by a slow, continuous, irreversible process of change called evolution. Diverse and complex forms evolved from simpler forms of life, without destroying the fundamental similarity of living beings. The features of basic unity are cellular structure, metabolism, replication and homeostasis. Evolutionary evidences also reveal that there is complementarity of structure and function.

The habitable part of the earth is an amazingly thin layer of about 22.4 km that forms the earth's crust. Lithosphere, hydrosphere and atmosphere together constitute the biosphere or the livable part of the crust. Living forms are unevenly distributed in the biosphere. A study of fossils has provided evidence that changes in living forms have occurred following random changes in the contours of the earth.

A major concern of ecology is the study of ecosystems. However small or large, ecosystems are maintained through interdependent mechanisms such as material cycles, food chain, food webs and energy flow. These mechanisms include the biotic and abiotic components of an ecosystem and maintain homeostasis.

The human species is unique and different from other animals in many ways. Endowed with a highly evolved brain and skilled hands, humans have gained dominance over other living forms. In spite of this distinct advantage, we are nearly insignificant as far as our position in the universe is concerned. Earth itself is a mere speck. Nevertheless, earth is our home and hence significant for us.

The dominance of human beings on this earth is traced to a cultural evolution. Galloping advances have been made in science and technology including exploration of space. Nevertheless, progress in every field has brought with it certain problems. Advances in industries have also resulted in depletion of natural resources, ecodegradation and pollution. Pesticides have increased crop yields, but new resistant varieties of pests have also emerged. Newer techniques in genetic engineering and medical science are bringing us fresh hope in combating disease and disorders, but can lead to certain malpractices. The problem of over-population is the root cause of many other problems.

We cannot be oblivious to progress-linked problems Development and progress must not be achieved at the cost of ecological security This requires a respect for nature as a life-supporting system

QUESTIONS

1 Tick the incorrect statement(s)
It is useful to study the origin and evolution of life because:
(a) We learn that life cannot exist anywhere else
(b) We learn about the unity and diversity of living organisms
(c) We learn that the human species has the responsibility to conserve nature.
(d) The human species is the most evolved, so no harm can come to us

2 Select the most appropriate statement
Scientists have undertaken a study of exobiology because
(a) Earth has become overcrowded
(b) People want to live in space
(c) It is human nature to explore the unknown
(d) The security of earth can be managed better

3. Fill in the blanks with suitable words
(a) During chemical evolution, the small molecules that played a crucial role in the origin of life were ____________, ____________, and ____________
(b) The most significant event in chemical evolution was the origin of ____________ type of molecules
(c) Primitive life was ____________ in nature.
(d) The evolution of ____________ molecule set the stage for the evolution of autotrophs.
(e) ____________, ____________, and ____________ together make up the biosphere.

4 Correct the statements that are wrong
(a) Human beings can live in complete isolation
(b) Biotic and abiotic components of ecosystem are interdependent
(c) An ecosystem refers to the living organisms regardless of the environment.
(d) We should use mineral resources very carefully because they are lost with the death of an organism

5. What is the argument in favour of the possibility of life existing elsewhere in space?

6 List the important features of water that may have favoured the origin of life in water

7 How are the phenomena of photosynthesis and respiration important in material cycle, as well as flow of energy?

8 Cite examples to demonstrate that scientific progress can also lead to certain problems and scientific knowledge can be misused

9 How do we ensure that our efforts towards improvement of the quality of life will not lead to the destruction of our natural resources and ecodegradation?

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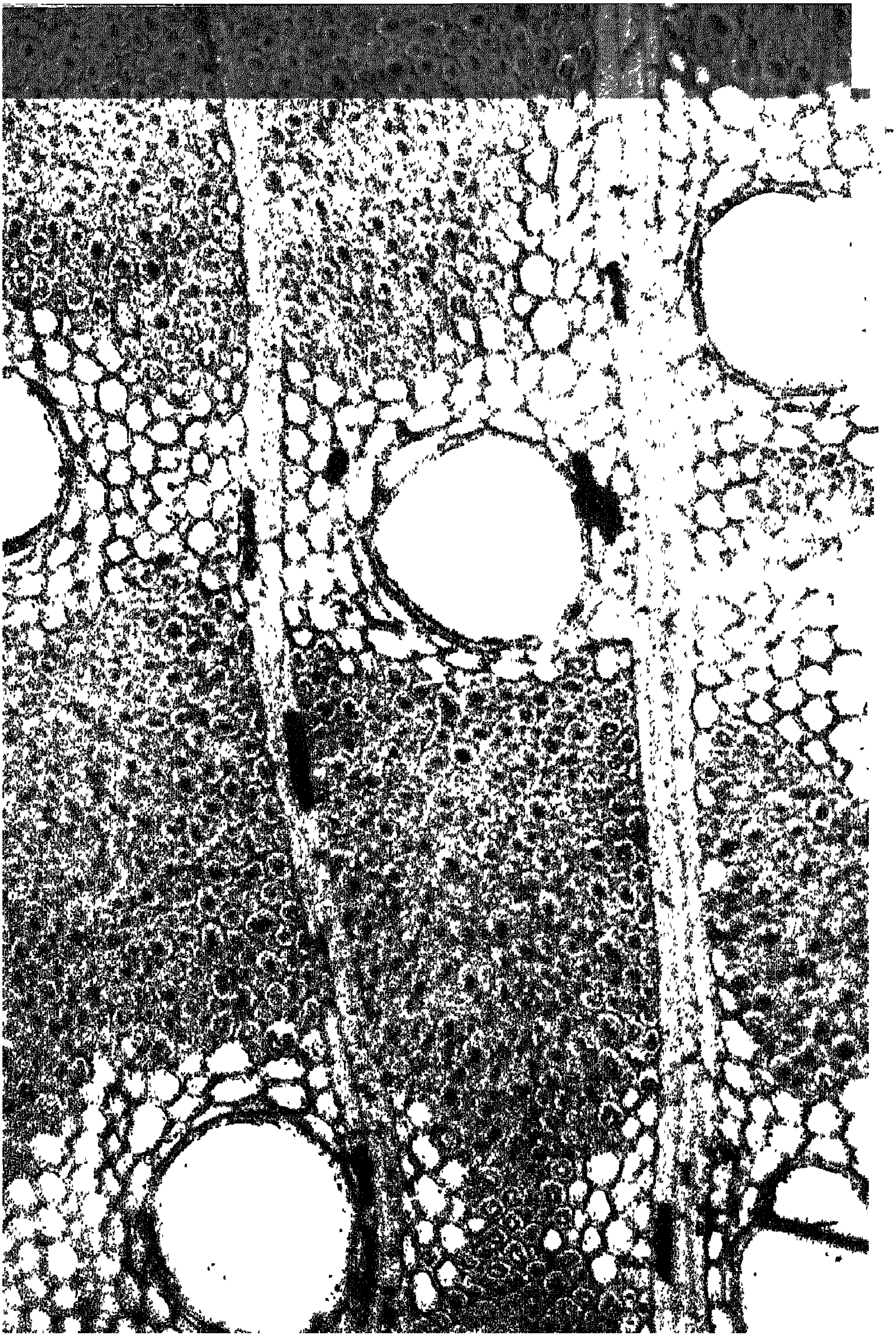


UNIT TWO

Unity of Life

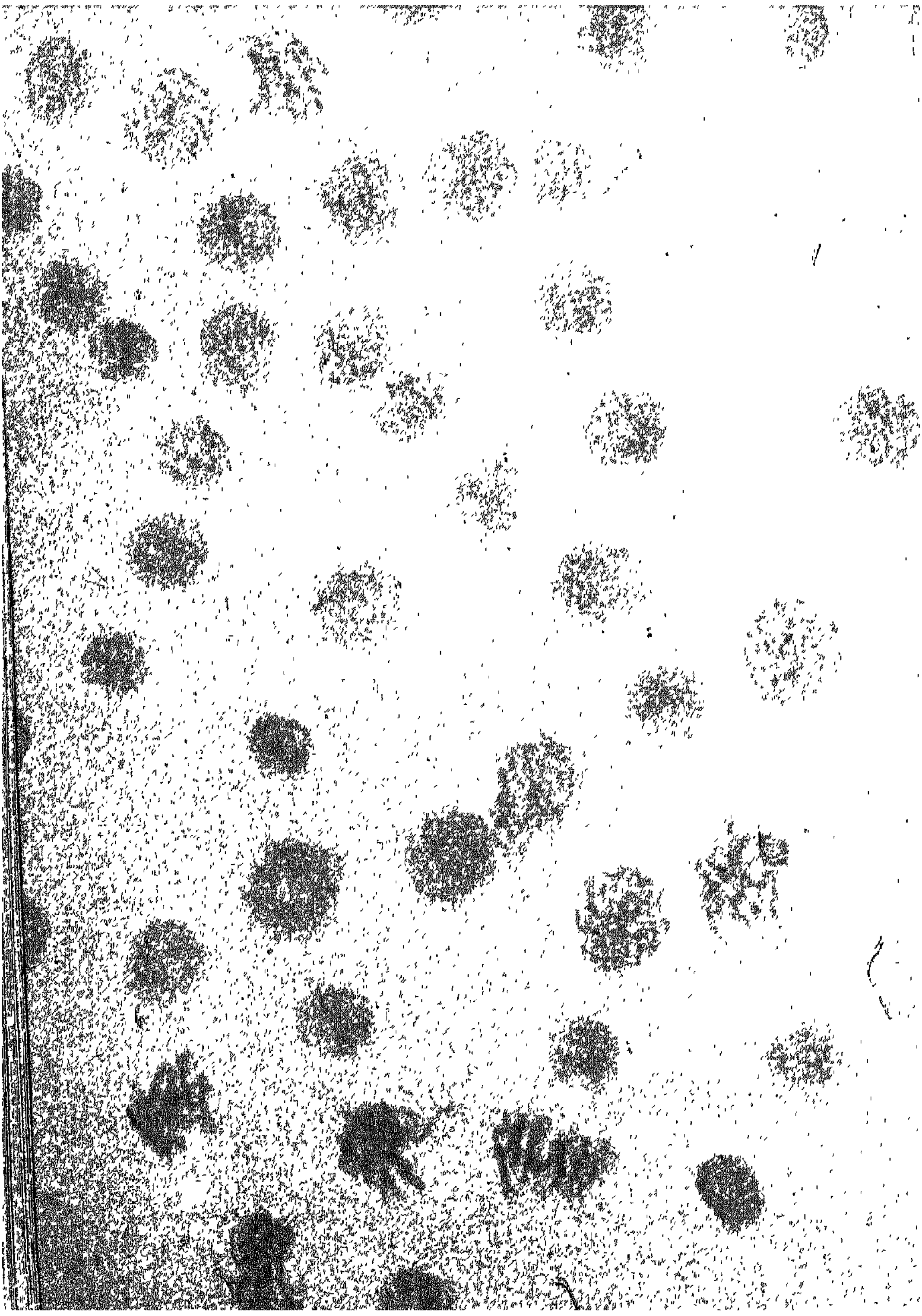
ORGANISMS display an immense diversity of form and size. Yet they have an underlying unity in their basic structure and processes. They are all made up of one or many cells. The uniqueness of an organism lies in the high degree of organisation at the molecular, sub-cellular and cellular levels. The contents of every cell are encased in a sheet-like structure called the plasma membrane. Membranes also enclose compartments of different composition such as mitochondria, chloroplasts and lysosomes in eucaryotic cells. Each sub-cellular compartment is called an organelle and performs distinct functions. Diverse types of cells show striking similarities between organelles like the nucleus. Across the membranes of all organisms, materials are exchanged by diffusion, osmosis and energy-dependent active transport.

As you have learnt in Unit One, all biological structures are made of molecules of a few specific types such as sugars, amino acids, water and minerals. Polymerisation of these molecules yields carbohydrates, proteins, lipids and nucleic acids. Biological membranes are made of two lipid layers with embedded proteins. The molecules that contain genetic information are the nucleic acids The structural components of organisms consist of carbohydrates, proteins and minerals. Additionally, certain carbohydrates and lipids serve as sources of energy.

Certain proteins called enzymes function as catalysts. In all organisms most chemical reactions are speeded up by enzymes. Enzymes are specific and function even outside an organism, provided necessary conditions are available.

All cells release energy from food molecules by aerobic or anaerobic respiration. Aerobic respiration occurs in mitochondria. Energy released by such processes is generally stored and utilised as adenosine triphosphate (ATP).

New cells are formed by divisions of pre-existing cells. The method of cell division is the same in some unicellular and all multicellular organisms.



CHAPTER 4

THE CELL AS A UNIT OF LIFE

NEARLY all livings things, from the tiniest to the largest, from the microscopic amoeba and single-celled algae to elephants and gigantic trees, are made up of cells. Many organisms consist of just one cell. They are called unicellular organisms. Others are composed of many cells. These are called multicellular organisms. The significance of 'many' in these organisms can be realised from the fact that several million cells are found in a drop of blood. In multicelled organisms cells become specialised to perform distinct functions.

A group of cells with similar structure and performing similar functions constitutes a TISSUE. Several types of tissues collectively form an organ which carries out one or more specific activities. In a highly evolved multicellullar organism such as man, several interrelated organs are arranged into an ORGAN SYSTEM, to carry out a particular life process. For example, the digestive system includes organs such as salivary glands, stomach, intestines, pancreas, liver and gall bladder, each composed of epithelial, connective and muscular tissues. But basically all are formed of several types of cells.

The Cell as a Basic Unit

The cell is now accepted as the basic unit of organisms. Our understanding of the cell required not only the development of the microscope, but also the ability to critically examine cells from a variety of organisms and identify their parts, using stains It has taken over 300 years of accumulated experience of numerous investigators to give us the present knowledge of cells A great number of questions about cells still remain unanswered. This is how science progresses The history of the cell begins with the publication of the classical work *Micrographia* in London by Robert Hooke in 1665

In 1665 Hooke observed a honeycomb-like pattern in a slice of cork under his primitive microscope. This honeycomb consisted of thick-walled, box-like compartments which he called cells for the first time. But he did not realise the real significance of these structures He considered those cork cells as structures forming passages for conducting fluids. Actually his

DISCOVERY OF THE CELL

Micrographia: Or Some Physiological Descriptions of Minutae Made by Magnifying Glasses, with Observations and Inquiries Thereupon by Robert Hooke, London 1665, is among the great classics of biology. The chapter which laid the foundations of cell biology as we know today is "Observ. XVIII. Of the Schematisme or Texture of Cork, and of the Cells and Pores of some other such Frothy Bodies" When you read the excerpts given below, you will realise that Hooke made his discoveries in spite of primitive cutting instruments, dim light sources and lenses with aberrations

"I took a good clear piece of Cork, and with a Pen-knife sharpend as keen as a razor, I cut a piece of it off, and thereby left the surface of it exceeding smooth, then examining it very diligently with a *Microscope,* me thought I could perceive it to appear a little porous, but I could not so plainly distinguish them if I could use some further diligence, I might find it to be discernable with a *Microscope,* I with the very same sharp Pen-knife, cut off from the former smooth surface an exceeding thin piece of it, and placing it on a black object Plate, because it was it self a white body, casting the light on it with a deep plano-concave Glass, I could exceeding plainly perceive it to be all perforated and porous, much like a Honey-comb in these particulars. .

Next in that these pores, or cells, were not very deep, but consisted of a great many little Boxes, separated out of one continued long pore, by certain *Diaphragms*...

'cells' were the cell walls enclosing the vacant spaces left by dead cork cells (Fig. 4 1).

Hooke did not restrict his studies to cork, but observed a wide range of plants under the microscope and concluded that they had the same structure. Hooke's observations based on diligence and perseverance, in spite of poor facilities, laid the foundation for further observations, which 16 decades later led to the formulation of the Cell Theory.

The microscope prompted scientists to look at a wide range of living things, to discover whether they contained Hooke's 'cells' A honeycomb-like pattern was seen in all plant tissues. Surprisingly, bits of animal matter examined did not contain the cells that were present in plants. An important discovery was the presence of a little

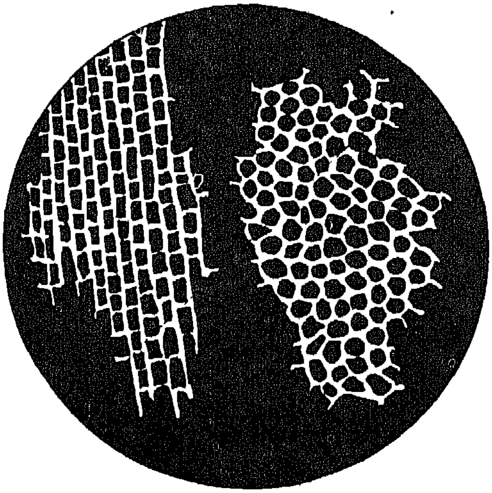


Fig. 4.1 "Cells" observed by Robert Hooke in a slice of cork

ORCHID

sphere in the cells of the orchid root by Robert Brown in 1831. This rounded body later called a NUCLEUS was a common occurrence in cells.

Schleiden (1804-1881), a German botanist, examined a large variety of plant tissues. He found all of them were composed of cells of some kind or other. He concluded in 1838 that cells are the ultimate units forming the structure of all plant tissues.

At the same time Theodore Schwann (1810-1882), a German zoologist closely studied many types of animal cells. He saw nuclei but not cell walls. The animal cells had a very thin outer layer which we now call PLASMA MEMBRANES. Schwann recognised that, apart from the cell wall which was unique to plants, the inside of both plant and animal cells was identical. Both had a nucleus and a clear substance around it Therefore he defined the 'cell' as a membrane-enclosed, nucleus-containing structure. After a thorough examination of plant and animal cells, he proposed a hypothesis: the bodies of animals and plants are composed of cells and products of cells

Schleiden and Schwann compared their data and discussed the Schwann's hypothesis. Their combined views led to the formulation of the Cell Theory. This theory, however, was not able to explain how new cells are formed. In fact Schleiden thought that cells were budded off from the nucleus. It was Rudolf Virchow (1855) who was the first to explain that cells divide , and that all new cells must come from pre-existing cells.

This narration illustrates how a hypothesis becomes a theory. A hypothesis (as proposed by Schwann), is a statement that needs to be tested. Confirmation of a hypothesis by years of verification (by Schleiden in this case) leads to a theory. The theory itself is modified as and when new discoveries are made (as by Virchow in this case).

The Cell Theory, as we now understand may be briefly summed up as follows.

1* All living things are composed of cells and their products

2* All cells arise from pre-existing cells.

3 * All cells are basically alike in chemical composition and metabolic activities.

4 * The function of an organism as a whole is the outcome of the activities and interactions of the constituent cells.

Acceptance of the Cell Theory raises a major question in biology. Is an organism a collection of independent cells that coexist and cooperate with one another? Or is an organism a group of independent cells whose functions are dictated by the needs of the organism? You will have many opportunities in the book to answer this question.

The cell is the fundamental structural and functional unit of all organisms All cells are closely similar in gross structure, molecular organisation and in certain basic activities The activities, whether of an organism or of its organs or tissues, are based on the activities of the cells that constitute them Thus an organism cannot demonstrate activities that are absent in its cells

What is common to all cells? The genetic material in all cells consists of nucleic acids. During cell division the hereditary characters are transmitted in the form of nucleic acids. The basic structure of the membranes and their properties are also common. The mechanism of aerobic respiration is strikingly uniform. Nucleic acids and proteins are synthesised on the same plan in all cells. Such fundamental similarities emphasise unity among all living organisms.

In spite of the basic unity explained above, organisms exhibit diverse forms and functions. These arise from specialisations developed by their cells during evolution.

The Cell as a Self-Contained Unit

Each cell acts as an autonomous unit It independently carries out all fundamental biological processes It oxidises food molecules to produce energy and utilises that energy and some nutrient molecules to synthesise complex molecules Further, the cell uses those molecules to build new structures and to replace those worn out The cell respires and exchanges gases with its surroundings. It reproduces cells with similar hereditary properties By regulating its own activities the cell maintains the necessary internal physico-chemical conditions Each cell has its own life span.

In a multicellular organism, cells do not normally live a totally independent existence They interact and cooperate with one another. By acquiring specialised structure and function, the cells in a multicellular organism develop a division of labour Yet, they remain partly dependent on one another A number of autonomous activities, like the ability to multiply, may be temporarily or permanently lost Yet, they retain the capacity for independent existence and multiplication This is easily demonstrated by the CELL CULTURE technique. In this technique cells are isolated from a multicellular organism and grown in a sterile nutrient medium under controlled conditions. The cells multiply and produce a large population of cells or a tissue, capable of all basic life processes

Unicellular and Multicellular Organisms

In a unicellular organism, its cell carries out all life processes, with the help of intracellular structures with characteristic forms called organelles The cell has to be sufficiently large to accommodate the numerous organelles. If a cell is to be efficient, the ratio of volume to surface should be within a limited range. An increase in cell volume is accompanied by a much smaller expansion in the surface area of the cell In other words, a large cell has a proportionately smaller surface and a higher volume:surface ratio than a smaller cell

Thus a large cell volume to accommodate many organelles simultaneously limits the exchange of information and materials through the surface This problem is partially overcome by developing a cylindrical shape or by forming numerous extensions of the cell membrane A single cell is unable to exhibit a wide range [illegible] differentiation. For instance, pliability is required for cell mobility Rigidity of the cell wall is needed for preventing it from bursting on account of the excessive inflow of water. But these two features cannot effectively coexist in a cell. A plant cell encased by a cell wall cannot move; a mobile leucocyte which has no cell wall is susceptible to overdistension with water in a dilute medium.

A multicellular organism, however, is not a simple aggregate of cells. Its cells are differentiated to share varied functions performed by a unicellular organism. For example, some cells synthesise extracellular materials to hold the cells together. Some transmit nerve impulses, while others are specialised to carry out reproduction. Even dead cells have their roles. The dead cells in the skin of animals and cork in plants protect the underlying living cells. Xylem vessels formed by a row of dead cells by the dissolution of cross walls, conduct water in flowering plants. Thus, a multicellular organism with its varied type of cells is considerably more efficient than a single-celled

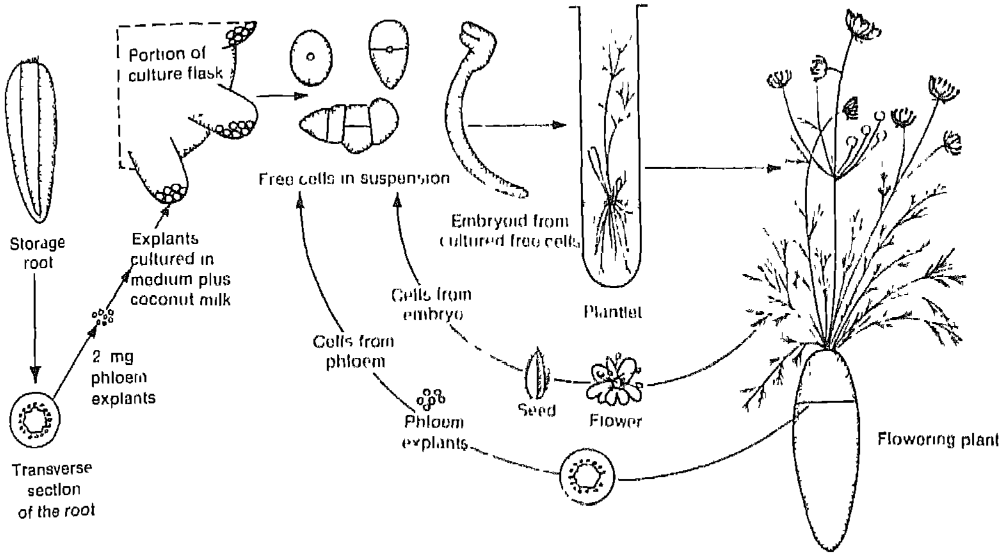


Fig. 4.2 Demonstration of cellular totipotency in carrot

PLANT CELLS ARE TOTIPOTENT

As early as 1902, a German botanist, Haberlandt, stated that every living plant cell should be able to regenerate a whole plant. This concept termed 'totipotency' was based on the understanding that as each cell of an organism is derived from the fertilised egg, it must contain the inherent capacity to produce the whole organism. However, Haberlandt's experiments to grow isloated cells of green leaves failed to demonstrate this hidden ability.

In the late 1950's F.C.Steward and his co-investigators at Cornell University, USA, carried out very interesting studies with carrots. These scientists took 2 mg pieces (explants) from phloem tissue of carrot roots composed of mature non-dividing cells. They grew them in liquid nutrient medium containing coconut water. The cells divided and dislodged to form a suspension. Clusters of newly formed cells developed roots. When these were transferred to culture tubes containing a semi-solid medium of the same composition, they formed shoots and ultimately plants. These test-tube plants when transferred to pots developed typical crunchy orange-coloured roots. This experiment showed that even mature cells can be made to divide and produce whole plants Subsequently Steward (1963) and Halperin and Wetherell (1964) demonstrated the production of thousands of somatic embryos (embryos formed from diploid vegetative cells) from carrot cells plated on a nutrient medium in petri dishes.

Totipotency of cells has now been repeatedly shown in a wide number of plant tissues of diverse origin (anther, endosperm nucellus, embryo, root, shoot-tips, leaf, flower buds, etc). This unique property of cells has been imaginatively employed for propagating plants through tissue culture.

organism.

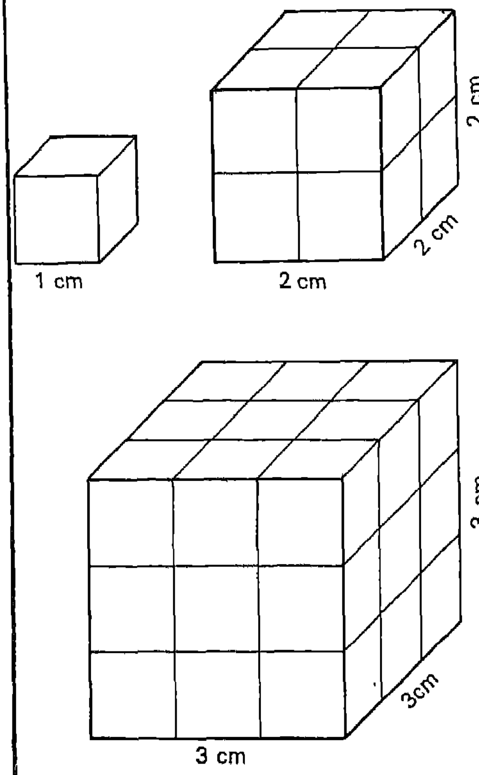


Fig. 4.3

SURFACE VOLUME RATIO

The first figure is a cube whose sides measure 1 cm. Its volume is thus 1 cubic cm. Its surface area is 6 square cm. Therefore its surface:volume ratio is 6·1

The second cube has sides measuring 2 cm or double that of the first cube Its volume is 8 cubic cm and its surface area is 24 square cm. Thus the surface.volume ratio is 3.1

If we take a cube whose sides are three times the first cubes (3 cm), its surface.volume ratio would be 2:1. So you see how the surface·volume ratio decreases with increasing size

In multicellular organisms many activities require that a number of cells work together For example, the heart pumps by well-coordinated movements of all its muscle cells A nerve impulse is transmitted by a series of nerve cells acting in sequence. This may be compared to a relay race in which individual runners of a team pass the baton in sequence. Thus, a cell has a dual existence—as an individual, and as a part of community.

Multicellular organism have a greater capacity for survival than unicellular ones. Death of a few cells may not be of serious consequence to them. Indeed, hundreds of dead cells are regularly replaced by the multiplication of surviving cells An abundant number of cells are shed everyday from the surface of the human skin and the inner lining of the intestine But they are soon replaced by new cells. Blood cells are continually destroyed and replaced by fresh ones produced in the bone marrow In contrast, damage may easily kill the unicellular organism

The human body has trillions of cells, all derived from the fertilised ovum and carrying the same genetic material Yet in many of its cells one or other basic activity may be suspended or irreversibly lost The mature human red blood cell loses its capacity for aerobic respiration, DNA replication and ribonucleic acid (RNA) synthesis. Mature nerve cells are incapable of division Liver cells and muscle cells retain mitotic ability but seldom divide normally. We do not yet know the reasons for the loss of certain activities.

Flow of Energy and Information

All living cells depend on the flow of energy and the flow of information As you have learnt in Chapter 2, according to the second law of thermodynamics every organism like other systems, has a tendency to increase disorderliness or ENTROPY. To maintain organisation at the molecular, cellular and organismic levels, the organism is compelled to collect energy from its surroundings and to use it continually to reduce entropy. Energy for this purpose is derived either from light photons or in the form of chemical bond energy from food (Fig 4.4)

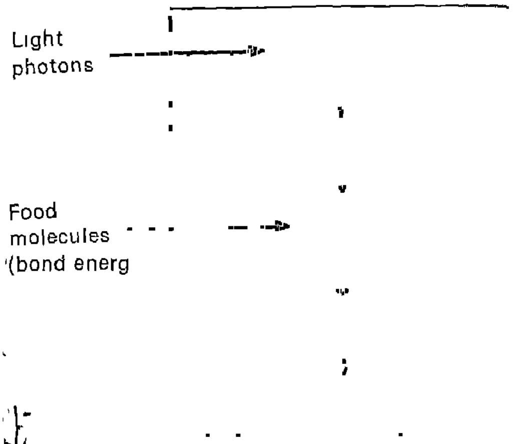


Fig 4.4 Flow of energy into a cell

The flow of information takes two routes ① The first is FLOW OF GENETIC INFORMATION The genetic information, contained in the DNA, is transcribed into RNA The information carried by RNA is translated into specific proteins. In other words, the kinds of proteins formed are determined by the molecular structure of DNA. The proteins in their turn perform and regulate all the activities of the cell (Fig. 4.5) The second is FLOW OF EXTRINSIC INFORMATION. Molecules like hormones pass information, coming from outside to the cell. Some of these enter the cell to influence its activities Others bind on to the cell surface with certain molecules that serve as RECEPTORS. Such binding leads to significant changes in cellular activities Studying the nature and action of such molecular receptors of cell membrane is an important line of modern research.

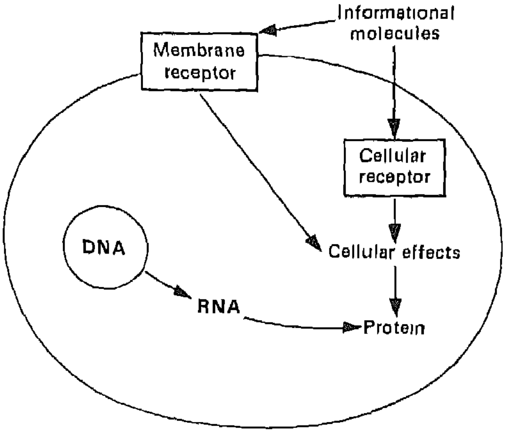


Fig. 4.5 Flow of information into a cell

Compartmentalisation for Cellular Life

Each cell may be considered as a compartment enclosed by a continuous membrane called the plasma membrane This membrane segregates the protoplasm within the cell and prevents it from mixing with the extracellular medium. This enables the cell to maintain a collection of molecules and well-regulated reactions. This is in sharp contrast to the more disorderly distribution and random interactions of molecules in the extracellular medium.

Interestingly, a cell is not a sealed compartment In a unicellular organism the plasma membrane allows selective exchange of materials between the cell and the outside. By allowing only certain molecules and ions to cross it, the cell maintains an internal composition, which is different from that of the surrounding medium.

In multicellular organisms the plasma membrane maintains the individuality of a cell, but does not totally isolate it from others. In animals, plasma membranes help the cells to recognise each other and aggregate in a tissue. The plasma membrane also allows the movement of not only certain materials but also messages between neighbouring cells and between the cells and outside. Organisms that live in the sea accumulate selectively certain substances from the sea water Some seaweeds can accummulate iodine so that the concentration within the cell is 2,000,000 times that of the sea water.

Compartments Within a Cell

Cells of animals, plants, fungi and protists (for example protozoans) have numerous intracellular compartments enclosed by membranes These are called membrane-bound ORGANELLES and include nucleus, mitochondria, chloroplasts, etc. There are also NON-MEMBRANOUS ORGANELLES such as centrioles and ribosomes These are not considered as compartments. Each organelle performs specific activities in a regulated and organised manner. Cells that contain organelles are called EUCARYOTIC CELLS (Fig. 4.6 & 4.8).

Bacteria do not possess membrane-bound organelles. Even the 'chromosome', is not enclosed in a membrane. Such cells are called PROCARYOTIC CELLS (Fig. 4.7). They carry out many biological processes that occur in eucaryotics cells. The absence of intracellular compartmentalisation indicates the primitive nature of procaryotic cells

Structure of Eucaryotic Cells

Eucaryotic cells vary considerably in shape and size. Unicellular eucaryetes usually measure 1-2 μm to 1 mm. Cells of multicellular organisms are mostly in the range of 5-100 μm, but may even reach 15-20 cm (ostrich egg). A striated muscle cell is 1-40 mm long and 30-80 μm in diameter. A human erythrocyte is 7-8 μm in diameter. Mean volumes of a few representative cells are given in Table 4.1.

SIZE OF HOOKE'S 'CELLS'

Robert Hooke (1635-1703) was basically a mathematician and a physicist. He joined the Royal Society in 1662 as Curator of Instruments, and was elected a Fellow next year at the early age of 28, an honour denied to many grey-haired scientists of today. The mathematician in him comes to the fore when he observes: "I told (counted) several lines of these pores, and found that there were usually about three score of these small cells placed endways in the eighteenth part of an inch in length, whence I concluded there must be eleven hundred of them or somewhat more than a thousand in the length of an inch, and therefore in a square inch about a million, or 1166400, and in a Cubick Inch, about twelve hundred Millions, or 125971200. A thing most incredible, did not our *microscope* assure us of it by ocular demonstrations. . ."

Table 4.1

MEAN VOLUMES OF REPRESENTATIVE CELLS AND VIRUS

Cell Type	*Volume (cubic μm)*
Ostrich egg	1.1×10^{15}
Hen egg	5.0×10^{13}
Human egg	1.4×10^{6}
Human sperm	1.7×10^{1}
Largest bacterium	7.0×10^{0}
Smallest bacterium	2.0×10^{-2}
Smallest virus	7.0×10^{-7}

A typical eucaryotic cell (Fig. 4.6) consists of a mass of jelly-like, translucent protoplasm, enclosed by a quasifluid PLASMA MEMBRANE. In plants the plasma membrane is surrounded by a rigid and porous cellulose wall (Fig. 4.8). The cell wall provides a distinct shape to the cell and prevents overdistension.

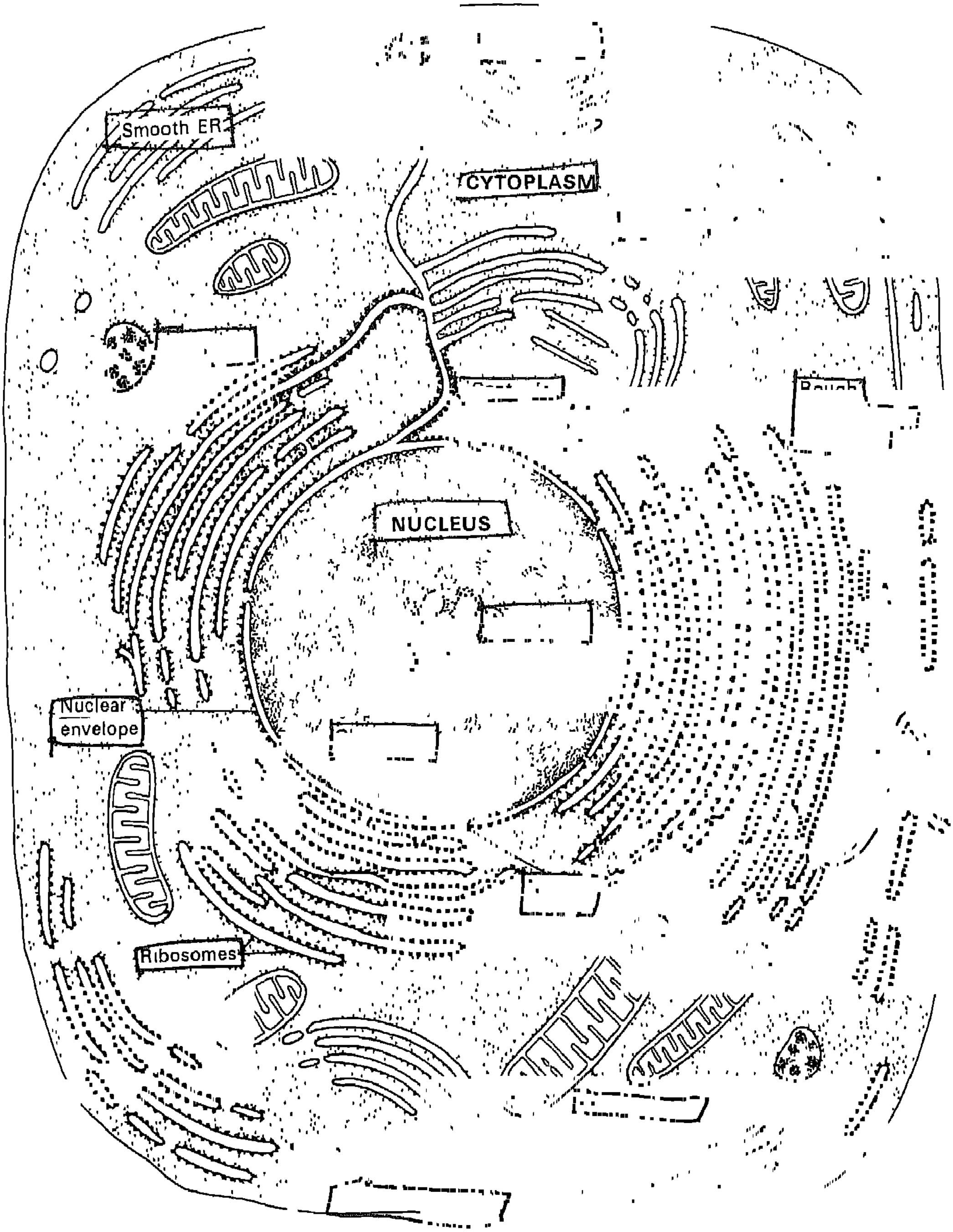


Fig 4 6 Eucaryotic cell of animal

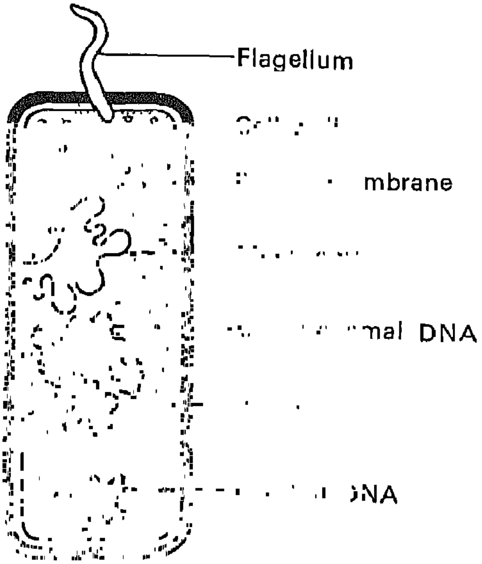
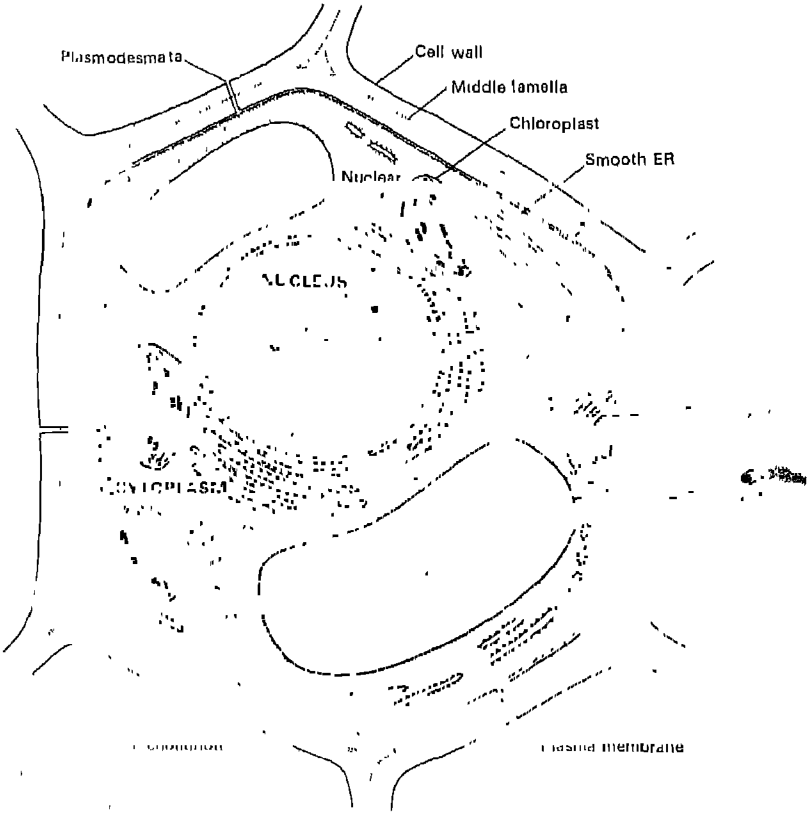


Fig. 4 7 Procaryotic bacterial cell

Not present

Fig. 4.8 Eucaryotic cell of plant



The general fluid mass of the cell outside the nucleus makes CYTOPLASM. The cytoplasm contains several organelles that can be identified on the basis of their appearance and chemistry when appropriately stained. The most prominent organelle of a cell is its NUCLEUS, which is enclosed by a double membrane. The nucleus is essentially a control centre or seat of organisation. VACUOLES are fluid-filled membranous vesicles. One or more spherical or oval vacuoles occur in the cytoplasm (Fig. 4.8). In mature plant cells, a large central vacuole spreads the protoplasm in a thin layer just inside the plasma membrane. The membrane around the vacuole is called the TONOPLAST. You will learn more about the nucleus and other cellular structures in Chapter 9.

SUMMARY

According to the Cell Theory, all living organisms are made of one or more cells. Cells are the basic units of living organisms. All cells arise from pre-existing cells.

Cells of all organisms have close similarities in structrure, molecular organisation and biological activities. These emphasise unity of life.

Each cell functions as a self-contained unit with considerable autonomy. It can independently carry out nutrition, respiration, growth, reproduction and self-regulation. In a multicellular organism, cells are not totally independent of one another. Some of their functions may not be operative. However, isolated living cells of multicellular organisms can be cultured for many generations in nutrient media. Thus the ability for independent existence is not lost by a cell even if it forms part of a specialised tissue in a multicellular body.

In a unicellular organism the single cell has to perform all its life processes. The presence of specialised structures called organelles helps the cell to carry out and regulate specific activities. In multicellular organisms distinct types of cells differentiate and perform different activities. The cells cooperate among themselves and participate in common functions.

Cells need a constant flow of energy for maintaining their organised structure and functions. This is obtained either through photosynthesis or from the chemical bond energy of food. Cells regulate their life processes with the help of continual flow of information. This may be genetic information carried by DNA or information coming from outside.

Compartmentalisation is essential for cellular life. The cell with its plasma membrane acts as a compartment. In plant cells the plasma membrane is surrounded by a cellulose wall. Eucaryotic cells possess many compartments, the membrane-bound organelles. Each organelle has a specific structure and function. Procaryotic cells do not show any intracellular compartments.

QUESTIONS

1 Indicate which of the following statements are true (T) or false (F).
   (a) Robert Hooke discovered the nucleus

(b) Cells are composed of highly independent and randomly interacting components
(c) Virchow stated that cells arise from pre-existing cells
(d) Intrinsic flow of information is required to maintain entropy
(e) The ostrich egg is the largest cell known

2 Observe the relationship between the first two words and then fill in the suitable word in the fourth place
(a) Bacteria : procaryote : Man ________
(b) Organs : organism : Cells : ________
(c) Cell : plasma membrane : Vacuole : ________
(d) Photosynthesis : energy :: DNA ________

3 Tick (√) the correct answer in each of the following cases:
(a) The procaryotic cells are characterised by
  (i) a distinct nuclear membrane
  (ii) distinct chromosomes
  (iii) absence of chromatin material
  (iv) absence of nuclear membrane
(b) Cells originate
  (i) by bacterial fermentation
  (ii) from pre-existing cells
  (iii) from abiotic materials
  (iv) by regeneration of old cells

4 What are the advantages for an organism to have tissues instead of the one type of cells?

5. Justify the statement "cell is the basic unit of life"

6 If, as the second law of thermodynamics states, "the free energy in any system tends to decrease," how is it that the earth maintains so many living organisms, each in a highly organised, high free-energy state?

7 What is meant by "flow of information"? What is the difference between extrinsic and intrinsic flow of information?

8. Who proposed the Cell Theory? Explain the main points of this Theory as it stands today

9 By means of a diagram compare the structure of a plant cell and an animal cell

10 Discuss how the method of science is reflected in the formulation of the Cell Theory.

CHAPTER 5

SMALL MOLECULES OF THE CELL

THE structure and functions of all cell components are determined by the molecular structure, arrangement and properties of their chemical constituents In this Chapter you will learn that cells exhibit a striking similarity in the nature of the small molecules and ions they contain Approximately 93 per cent of the cellular material is composed of carbon, hydrogen and oxygen The non-metal elements nitrogen, phosphorus, .chlorine and sulphur form about 2 per cent of the total material in the cell, whereas iodine, fluorine, boron and selenium occur in traces. Less than 5 per cent of cellular constituents comprise major metal elements such as calcium, potassium, sodium and magnesium. Traces of copper,cobalt, zinc, manganese, molybdenum and chromium are found.

The Cellular Pool

The collection of various types of molecules in a cell is termed the CELLULAR POOL This cellular pool consists of water, inorganic materials and organic compounds Inorganic materials include salts, mineral ions and water. Organic compounds consist mainly of carbohydrates, lipids, amino acids, proteins, nucleotides, nucleic acids and vitamins. Some organic molecules remain in colloidal form in the aqueous intracellular fluid Others exist in nonaqueous phases like the lipid membranes and cell walls In animals, the cellular pool has a composition which is quite different from that of the extracellular fluid. This distinction is maintained by the selective permeability of the plasma membrane. The cell maintains a constancy of the pool by the intake and elimination of specific molecules.The cellular pool provides materials for the structure and functions of the cell

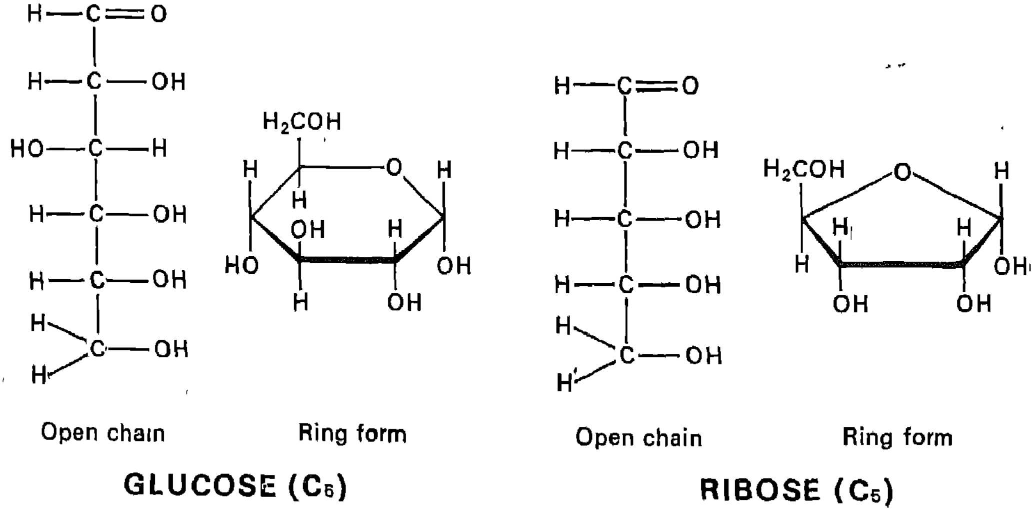
The small molecules found in the cellular pool have low molecular weights (MW), simple molecular conformations and usually higher solubilities These include minerals, water, amino acids, sugars, lipids and nucleotides. Polymerisation of a large number of small molecules gives rise to MACROMOLECULES, such as proteins, nucleic acids and certain polysaccharides. You will learn more about the composition and roles of these macromolecules in the next chapter

Carbohydrates $C_n H_{2n} O_n$

Carbohydrates are basic components of our food You also know that carbohydrates are the principal source of energy for the body. What are these compounds? Carbohydrates are mainly compounds of carbon, hydrogen and oxygen. Carbohydrates are so called because in most of them the proportion of hydrogen and oxygen is the same as in water (H_2O) and the general formula may be written as $C_nH_{2n}O_n$ Carbohydrates also possess more than one alcoholic -OH group Carbohydrates are produced by green plants during photosynthesis About 80 per cent of the dry weight of plants is made of carbohydrates.

Carbohydrates are known as saccharides or compounds containing sugar. The simplest carbohydrates are the simple sugars or MONOSACCHARIDES, many of which have the general formula $C_nH_{2n}O_n$. These cannot be hydrolysed into still smaller carbohydrates. Monosaccharides are composed of 3 to 7 carbon atoms They are classified according to the number of carbon atoms Monosaccharides with 3,4,5,6 and 7 carbons are classified as trioses ($C_3H_6O_3$), tetroses ($C_4H_8O_4$), pentoses ($C_5H_{10}O_5$), hexoses ($C_6H_{12}O_6$) and heptoses ($C_7H_{14}O_7$) in that order. Hexoses and pentoses exist in both open chain and in ring forms (Fig 5 1). Glucose, fructose and galactose are hexoses They are all white, crystalline, sweet-tasting substances, extremely soluble in water Ribose is a pentose (Fig 5.1) and glyceraldehyde and dihydroxyacetone are trioses These compounds have very important roles to play in the metabolism of cells as you will learn later. Glucose is the most important sugar occurring in animals Fructose is the commonest form of sugar in fruits Deoxyribose which occurs in deoxyribonucleic acid (DNA) is a pentose (Fig. 5.2).

Monosaccharides have two important chemical properties Sugars having a free *aldehyde* or *ketone* group can reduce Cu^{++} to Cu^{+}. These are called *reducing-sugars*. This property is the basis for Benedict's test


Open chain Ring form

GLUCOSE (C_6)

Open chain Ring form

RIBOSE (C_5)

Fig. 5 1 Open chain and ring forms of monosaccharides

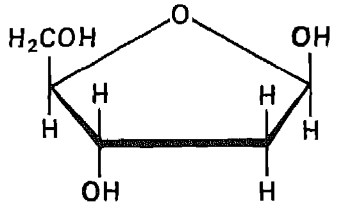


Fig. 5.2 Deoxyribose in ring form as it occurs in DNA

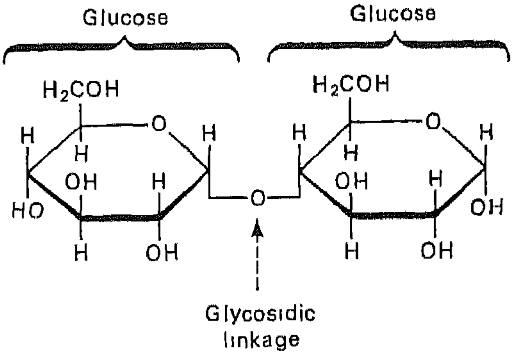


Fig. 5.3 Maltose, a disaccharide made of two glucose molecules

and Fehling's test to detect the presence of glucose in urine The aldehyde or ketone group of a monosaccharide can react and bind with an alcoholic group of another organic compound to join the two compounds together. This bond is called the GLYCOSIDIC BOND. This bond can be hydrolysed to give the original compounds.

Monosaccharides by joining together through glycosidic bonds give rise to COMPOUND CARBOHYDRATES (Fig 5 3) The latter can be hydrolysed into the component monosaccharides by acid or enzyme. Compound carbohydrates can be classified into two major groups, OLIGOSACCHARIDES made of a few molecules of monosaccharides, and POLYSACCHARIDES composed of hundreds of simple sugar molecules You will learn more about polysaccharides in the next chapter.

DISACCHARIDES are composed of two monosaccharides A molecule of sucrose is formed from a molecule of glucose and one of fructose Sucrose does not reduce Cu^{++} to Cu^{+}. However, if it is hydrolysed to produce glucose and fructose, then the hydrolysed solution gives the Benedict's test Sucrose is the storage product of photosynthesis in sugarcane and sugarbeet Lactose or milk sugar is found in human milk and cow's milk. It is formed from one glucose molecule and one of galactose Maltose or malt sugar is formed ~~from two~~ molecules of glucose (Fig. 5 3) during germination of starchy seeds. Maltose ~~and lactose~~ are reducing disaccharide. Fructose is the sweetest among naturally occurring sugars. Cell membranes contain larger oligosaccharides which may be branched.

Function of Small Carbohydrates. Small carbohydrates, particularly the monosaccharides have a pivotal role in metabolism. Trioses, pentoses, and heptoses are intermediates in the pathway of photoshynthesis leading to the synthesis of hexose (glucose). Glucose is broken down during respiration, by every living cell, to release energy. Glucose is the blood sugar of many animals. Tissue cells draw glucose from blood and oxidise it for obtaining energy. Mammary glands synthesise lactose of milk from glucose and galactose. Ribose and deoxyribose are components of nucleic acids and nucleotides. Glucose is utilised in synthesising fats and amino acids. Monosaccharides are polymerised into compound carbohydrates. These may be either structural polysaccharides such as cellulose and lignocellulose of plant cell wall, and oligosaccharides of membranes, or food-storage polysaccharides such as starch and glycogen

Lipids Fatty acid

You may not have come across the term

lipid in everyday life But you are familiar with a number of substances like cooking oil, butter, ghee, waxes, natural rubber and cholesterol. These are either lipids or rich in lipids. Cell membranes, plant pigments like carotene found in carrots and lycopene that occurs in tomatoes, vitamins A, E, and K, menthol and eucalyptus oil also belong to the same category. Lipids exhibit a variety of structures but have certain common characteristics. They are all made of carbon, hydrogen and sometimes oxygen The number of oxygen atoms in a lipid molecule is always small, compared to the number of carbon atoms. Sometimes small amounts of phosphorus, nitrogen and sulphur are also present Lipids are insoluble in water, but soluble in non-polar solvents like chloroform and benzene.

FATTY ACIDS are organic acids with a hydrocarbon chain ending in a carboxyl group (COOH) (Fig.5.4). Fatty acids are called *saturated* if they do not have any double bonds between the carbons of the molecular chain e.g , palmitic acid (16 C) and stearic acid (18 C) UNSATURATED FATTY ACIDS have one or more double bonds between the carbons of the chain The 18C unsaturated fatty acids oleic, linoleic and linolenic acids have 1, 2, and 3 double bonds respectively The unsaturated fatty acids have lower melting points than saturated fatty acids. In lipids, fatty acids are usually in the form of esters. Just as acids and bases react to form salts, similarly organic acids react with alcohols to form esters.

$$CH_3(CH_2)_{16}COOH$$

Stearic acid

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$$

Oleic acid

Fig. 5.4 Saturated and unsaturated fatty acids

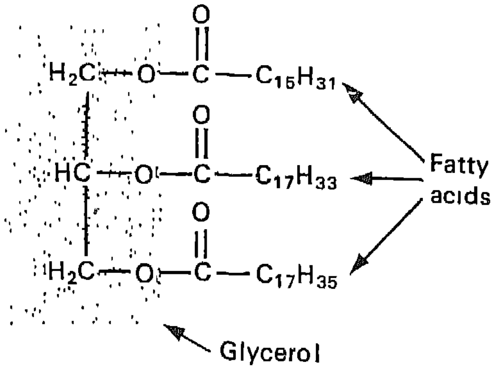


Fig 5.5 A triglyceride fat

FATS are esters of fatty acids with glycerol (glycerine) (Fig. 5.5) Each molecule of glycerol can react with three molecules of fatty acids. Depending on the number of fatty acids that are attached to the glycerol molecule, the esters are called mono-, di-, or tri- glycerides. Fats that are generally liquid at room temperature are called *oils*. Oils are rich in unsaturated fatty acids and consequently have low melting points e.g., groundnut oil, rape seed and mustard oil, sesame seed oil (til oil) and safflower oil You may have read advertisements of vegetable oils claiming to be "rich in polyunsaturates". This means that the fatty acids present in this oil have more than one double-bond. Such oils are recommended by physicians for persons who suffer from high blood cholesterol or cardiovascular diseases. This is because increasing the proportion of polyunsaturated fatty acids to saturated fatty acids, without raising the fat in the diet tends to lower the high blood cholesterol level found in certain individuals. In hydrogenation the unsaturated acids become saturated and the oil becomes a solid fat ("Vanaspati" and margarine).

Waxes are another class of lipids. They are formed by the combination of a long-chain fatty acid with a long chain alcohol. Waxes have an important role to play in protection. They form water-insoluble coatings on hair and skin in animals and stems, leaves and fruits of plants.

There are other types of lipids occurring in the cell. The commonest among them are the PHOSPHOLIPIDS These lipids contain not only a fatty acid and an alcohol but also a phosphate group Hence the name phospholipid. Some phospholipids also have a nitrogenous compound such as choline attached to them. Phospholipid molecules carry both hydrophilic (water-attracting) polar groups and hydrophobic (water-repellant) nonpolar groups The hydrocarbon chains of the fatty acids are the NON-POLAR TAILS of the molecule. The phosphate and the nitrogenous/non-nitrogenous groups form the POLAR HEAD-GROUP of the molecule (Fig. 5 6). Many phospholipid molecules may arrange themselves in a double-layered membrane (LIPID BILAYER) in aqueous media (Fig. 5.7). This results from the simultaneous presence of both polar and non-polar groups in the molecule Such lipid bilayers are the basic components of cell membranes (see Chapter 8). Another class of lipids are the GLYCOLIPIDS. These have one or more simple sugars.

The above-mentioned lipids are mainly straight chain compounds. There is a third class of lipids which are not straight chain compounds. They are called STEROLS. You may have heard of cholesterol being present in the human body. The sterols are composed of fused hydrocarbon rings and a long hydrocarbon side chain. Cholesterol (Fig. 5 8) is found in animals only. It exists either free or as CHOLESTEROL ESTER with

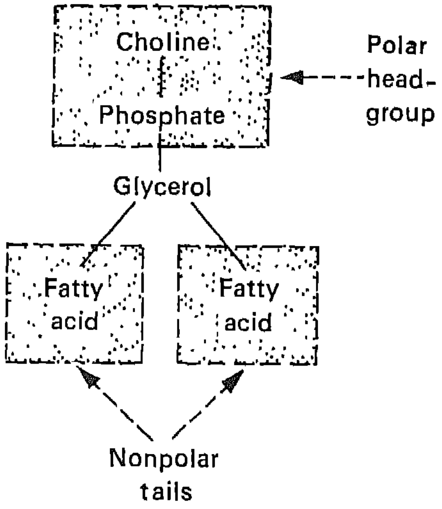


Fig. 5.6 A phospholipid molecule (lecithin) showing polar head-group and non-polar tails

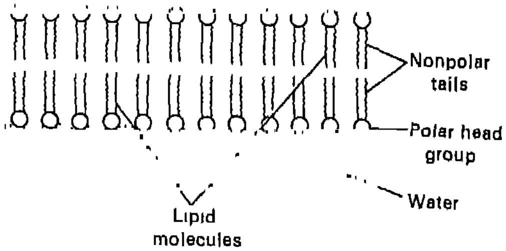


Fig 5.7 Lipid bilayer in aqueous medium

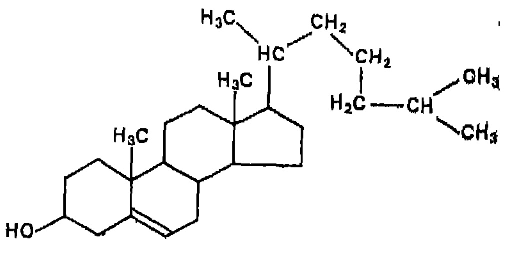


Fig 5.8 Cholesterol

a fatty acid. Cholesterol is also the precursor of hormones such as progesterone, testosterone, estradiol and cortisol. Cholesterol and its esters are insoluble in water. So they are deposited in the arteries and veins if the blood cholesterol rises. This leads to high blood pressure and heart diseases. Another steroid compound, *diosgenin* produced by the yam plant (Dioscorea) is used in the manufacture of antifertility pills.

Functions of Lipids Fats are storage products in plants as well as animals. In oil-seeds such as groundnut, mustard, coconut, and castor, the fat is stored by the plants to provide nourishment for the embryo during germination Oil extracted from these seeds is used for cooking and other purposes. In animals the fat droplets are found in the ADIPOCYTES. Fats are the most highly concentrated source of energy for man They are oxidised for energy when necessary Fats deposited beneath the skin and around the internal organs minimise loss of body heat and also act as cushions to absorb mechanical impacts

Phospholipids, glycolipids, and sterols serve mainly as structural lipids They are important components of membranes Cholesterol is the most important sterol in animals It forms a part of the animal cell membrane and is also used in the synthesis of steroid hormones, Vitamin D and bile salts.

Amino Acids

Protein is an essential food for growth and development. Proteins are macromolecules composed of certain kinds of amino acids. Plants and some microorganisms are able to synthesise amino acids from inorganic nitrogen sources (see Unit Five) However, animals cannot utilise inorganic nitrogen, and are therefore dependent on plants either directly (herbivores), or indirectly (carnivores), for the supply of essential amino acids C H O N

Amino acids are small molecules made of carbon, hydrogen, oxygen and nitrogen, and in some cases also sulphur. They are monocarboxylic or dicarboxylic acids bearing one or two amino groups. The a-carbon is next to the carboxyl-C. The four valences of the a-carbon of an amino acid hold respectively an amino (NH_2) group, a carboxyl (COOH) group, a hydrogen atom and a SIDECHAIN (Fig. 5.9). The sidechain may be polar or non-polar (Fig. 5 10)

A free amino group is basic; a free carboxyl group is acidic Lysine and arginine are BASIC AMINO ACIDS because they carry two amino groups and one carboxyl group

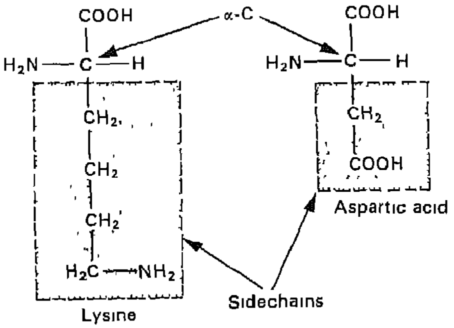


Fig. 5.9 Side chain of a basic and an acidic amino acid

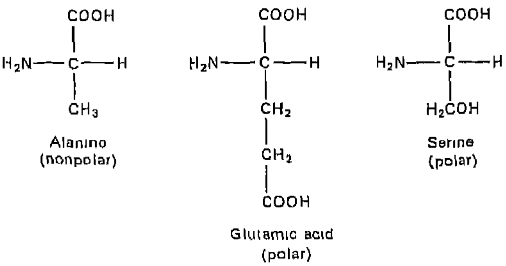


Fig. 5.10 Examples of polar and non-polar amino acids

(Fig. 5.9) Glutamic acid (glutamate) and aspartic acid (aspartate) contain one amino and two carboxyl groups each and are classified as ACIDIC AMINO ACIDS. Alanine, glycine, valine and phenylalanine are NEUTRAL AMINO ACIDS as these contain one amino and one carboxyl group.

AMINO ACIDS WHICH OCCUR IN PROTEINS

Glycine, alanine, serine, cysteine, aspartic acid, glutamic acid, asparagine, glutamine, methionine, threonine, valine, leucine, isoleucine, lysine, histidine, arginine, phenylalanine, tyrosine, tryptophan and proline.

Two amino acids can be linked by the formation of a peptide bond. Successive amino acids may be linked by PEPTIDE BONDS to form a linear chain of many amino acids (Fig. 5.11). When a few amino acids are joined together, the molecule is called a peptide. Proteins are macromolecules formed from a large number of amino acids. They are distinct from amino acids and small peptides in many properties. You will learn more about the structure and function of proteins in the next chapter.

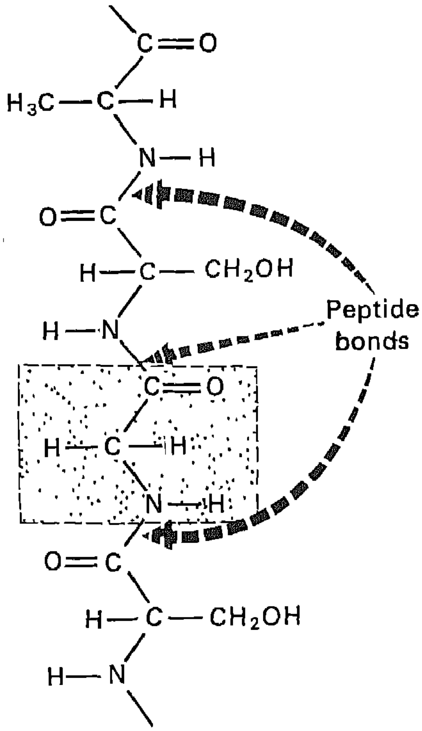


Fig. 5.11 A part of a peptide showing peptide bonds linking amino acids. One amino acid is shown in stippled box

Functions of Amino Acids Besides their principal function as building blocks for proteins, specific amino acids are also converted into different types of biologically active compounds For example, tyrosine is converted into the hormones thyroxin and adrenaline, as well as the skin pigment melanin, glycine is involved in the formation of heme and tryptophan in the formation of the vitamin nicotinamide as well as the plant hormone indole-3-acetic acid After the removal of the amino group the carbon chain of many amino acids is converted into glucose. On losing the carboxyl group as carbon dioxide, amino acids form biologically active amines such as histamine

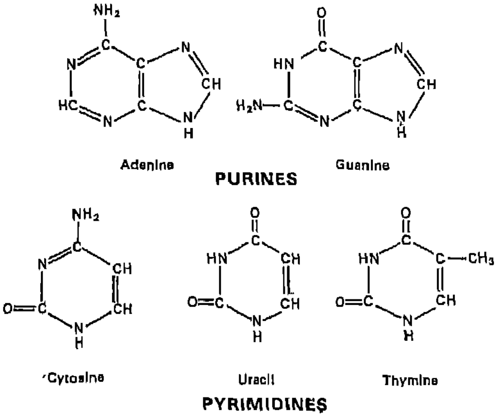
Nucleotides

This is a group of small complex molecules forming a part of the information transfer system in cells. They are basic units of nucleic acids They also participate in energy transfer systems. C H

Nucleotides contain carbon, hydrogen, O oxygen, N nitrogen and P phosphorus. Each nucleotide is made up of a cyclic nitrogenous base, a pentose and one to three phosphate groups. The nitrogenous bases occurring in nucleotides are either a purine or a pyrimidine. Major purines are adenine and guanine. Thymine, uracil and cytosine are the major pyrimidines (Fig 5.12). The pentose is either ribose or deoxyribose. The nucleotides are thus called ribonucleotides or deoxyribonucleotides Examples of ribonucleotides and deoxyribonucleotides are adenylic acid (AMP) and deoxyadenylic acid (d AMP) respectively. Ribonucleotides are the basic units of ribonucleic acids (RNA), and deoxyribonucleotides are the basic units of deoxyribonucleic acids (DNA). A combination of the nitrogenous base with the pentose sugar is known as a NUCLEOSIDE. For example, adenosine is a nucleoside made of adenine and ribose The nucleotides are thus called RIBONUCLEOTIDES or DEOXYRIBONUCLEOTIDES. Examples of ribonucleotide and deoxyribonucleotide are adenylic acid (AMP) and deoxyadenylic acid respectively. Ribonucleotides are the basic units of ribonucleic acid (RNA), and deoxyribonucleotides are basic units of deoxyribonucleic acids (DNA)

Nucleotides are mono-, di-, or triphosphates of nucleosides. For example, adenylic acid or adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) are all adenine nucleotides. Nucleotides with more than one phosphate group are called higher nucleotides, e.g , ATP and ADP (Fig. 5.13). Likewise, other purines and pyrimidines can also form higher nucleotides.

Fig. 5.12 Some purine and pyrimidine bases



Higher nucleotides of purines and pyrimidines occur in the free state, e g , ATP, ADP. Their third and second phosphate bonds can release about 8 kcal or more of free energy per mol on hydrolysis. This far exceeds the energy released on hydrolysis of most other covalent bonds. So, these phosphate bonds of the higher nucleotides are called HIGH-ENERGY BONDS (Fig. 5 13).

Nucleotides of the vitamins nicotinamide and riboflavin (Table 5.1) occur either free

Fig. 5.13 Ribonucleotides of adenine ∿ indicates high-energy bond

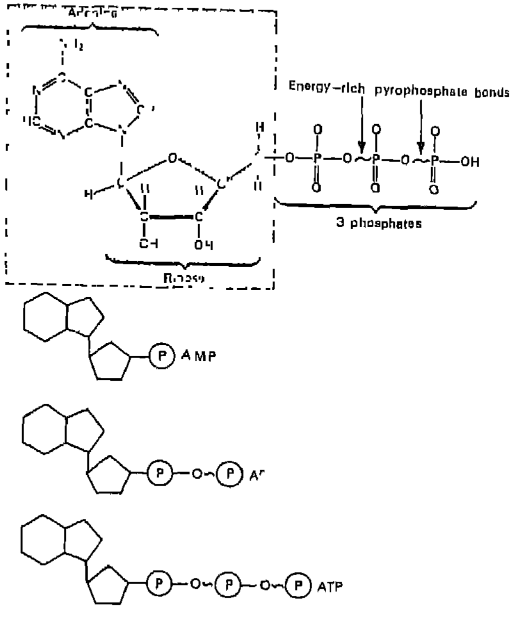


Table 5.1

NICOTINAMIDE AND RIBOFLAVIN NUCLEOTIDES

Vitamin	*Nucleotide*	*Components*
Nicotinamide	Nicotinamide adenine dinucleotide or NAD^+	Nicotinamide-ribose-phosphate-phosphate-ribose-adenine
	Nicotinamide adenine dinucleotide phosphate or $NADP^+$	Nicotinamide-ribose-phosphate-phosphate-phosphoribose-adenine
Riboflavin	Flavin mononucleotide or FMN	Riboflavin-phosphate
	Flavin adenine dinucleotide or FAD	Riboflavin-phosphate-phosphate-ribose-adenine

or in combination with specific proteins They do not participate in the formation of nucleic acids Instead, they act along with oxidising enzymes and participate in oxidation reactions occurring in the cell.

Functions of Nucleotides : Purine and pyrimidine nucleotides polymerise to form nucleic acids. Higher purine and pyrimidine nucleotides, particularly ATP, store energy in their high-energy phosphate bonds They are formed during photosynthesis and respiration Hydrolysis of the phosphate bonds of ATP releases their bond energy for driving energy-dependent reactions and processes. Nicotinamide and riboflavin nucleotides act as coenzymes of oxidising enzymes.

Minerals

Minerals occur in living organisms as components of organic and inorganic molecules and ions In all body fluids there is a balance between the amounts of a mineral present as ions and in complexes. Major minerals of the animal body are calcium, phosphorus, sodium, chlorine, magnesium and sulphur. Some other minerals occur in very small amounts, e g , iron, copper, cobalt, manganese, molybdenum, zinc, fluorine, iodine, and selenium. The minerals essential for plant growth are divided into groups. The mineral elements required in large amounts are termed macronutrients and include phosphorus, potassium, calcium, magnesium, sulphur and iron. Minerals required in trace amounts are known as micronutrients. These are manganese, cobalt, zinc, boron, copper, molybdenum and chlorine. You will learn more about mineral nutrition of plants in Unit Five. The same mineral can play a number of different roles. These roles and the elements participating in them are discussed below.

Minerals which form Part of Cellular Structure

Many mineral elements enter the structure of cellular components. Sulphur containing amino acids also enters into proteins Calcium imparts strength and rigidity to bones and teeth by [illegible] along with phosphates. So high are the contents of calcium and phosphorus in the bones, that bone dust is used as fertiliser. Calcium carbonate forms the exoskeleton of invertebrates. Shells of molluscs are burnt to yield lime (CaO). In plants calcium pectate forms the middle lamella. The usefulness of phosphorus in the formation of some basic molecules like lipids and nucleotides has already been emphasised.

Magnesium also contributes to the rigidity of bones and teeth

Minerals as Part of Biologically Active Substances : You are aware that iron deficiency leads to anaemia. This is because of a failure in *hemoglobin* synthesis Iron (Fe^{2+}) combines with the pigment porphyrin to form *heme*. The latter binds with different proteins to form RESPIRATORY PIGMENTS that help in respiration These include the oxygen-carrying pigment hemoglobin of erythrocytes and the oxygen-storing pigment MYOGLOBIN of muscle cells. *Cytochromes* are heme-protein complexes acting as oxidising enzymes You will learn more about their function in cellular respiration in Chapter 10. The plant pigment chlorophyll is a complex of magnesium (Mg^{2+}) and porphyrin along with a long lipid tail.

Iodine occurs in mammals as inorganic iodides, protein-bound iodine of blood and thyroid hormones. Dietary deficiency of iodine depresses thyroid activity and enlarges the thyroid gland (*goitre*). The soils of northern hill regions of India are deficient in iodine; so are the crops and drinking-water. Consequently goitre is widespread among the people of these regions. Steps are being taken to overcome this disorder by supplying iodised common salt.

Minerals and Enzyme Action · Mineral elements present in trace amounts are mostly required for enzyme action. For instance, manganese is required for the activity of enzymes needed for the synthesis of oligosaccharides and glycoproteins. Mitochondria are rich in manganese. Molybdenum is necessary for fixation of nitrogen catalysed by nitrogenase. Copper occurs in cytochrome oxidase Magnesium is essential for a large number of enzymes, particularly those utilising ATP.

Other Roles of Minerals Sodium and potassium are responsible for the maintenance of fluid balance Volumes of extracellular and intracellular fluids are maintained by the osmotic effects of the concentration of these two ions. These two ions are also responsible for the maintenance of membrane potential. You will learn more about these two functions when you study the cell mambrane. $Na^+$and K^+ ions are also responsible for the transmission of electrical impulses in the nerve cells. However, calcium and magnesium reduce the excitability of nerves and muscles In both cells and extracellular fluids dibasic phosphate (HPO_4^{2-}) and monobasic phosphate ($H_2PO_4^-$) neutralise strong acids and bases respectively So they act as *acid-base buffers* to maintain the H^+ ion concentation of cellular fluids.

Water

Water is unique in many ways for supporting life. You have already studied the importance of water in Chapters 2 and 3. Water is the most abundant substance in any living organism. In man, about 55 per cent of the body water (20–22 litres) is confined to cells as intracellular water. The remainder is found in extracellular fluids like blood, tissue fluid and lymph. Water is a tiny molecule and flows readily through the membranes.

Water acts as the solvent in living organisms Several water molecules are hydrogen-bonded to form short-lived macromolecular aggregates. HYDROGEN BOND is a non-covalent bond formed by the sharing of a hydrogen by two electronegative atoms like the oxygens of two water molecules Such hydrogen bonding of several water molecules forms a lattice structure (Fig 5 14) Fluidity of water is maintained by very rapid formation and dis-

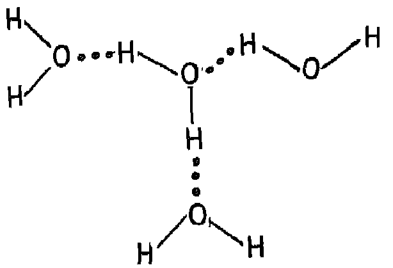


Fig 5.14 Hydrogen bonding of water' molecules

sociation of hydrogen bonds between water molecules To dissolve in water, a solute molecule must form hydrogen bonds with water molecules to join this lattice structure Hydrophilic polar groups of solutes can form hydrogen bonds with water molecules So, polar molecules join the lattice structure of the latter and dissolve in water This solvent action of water enables the dissolved polar solutes such as glucose to diffuse uniformly in cytoplasm and to be transported in extra-cellular fluids

But hydrophobic nonpolar groups cannot join the lattice structure of water So nonpolar molecules such as fats do not dissolve in water and have to be transported in water in association with polar molecules

Water maintains molecular conformations and stabilises structural organisation of living matter. In aqueous body fluids, proteins and nucleic acids become folded and coiled to assume specific 3-dimensional forms suitable for biological activity. Interaction between water and phospholipid molecules arranges the latter into the lipid bilayer of the membrane. (Fig. 5 7)

Water ionises to a small but significant extent into H^+ and OH^-, depending on the temperature Proteins, nucleic acids and phospholipids attain specific ionic states by accepting or donating H^+ from or to water Mineral salts also ionise in an aqueous medium of the cells

Owing to its solvent action, water forms an ideal medium for chemical reactions. The solute molecules and ions intermix and make intimate contact with each other. Water is a reagent and is a source of H^+ and OH^- for many biochemical reactions During photosynthesis, water donates the electron to chlorophyll and is thereby oxidised to molecular oxygen

Water helps in maintaining the constancy of the internal environment of an organism. Some substances, capable of neutralising acids or bases, remain in solution in the cytoplasm as extracellular fluids, e g , bicarbonate (HCO_3), carbonic acid, dibasic phosphate (HPO_4^{2-}) and monobasic phosphate ($H_2PO_4^-$). Acids and bases mix in the body fluids with these substances and are neutralised by them. Because of its solvent action water aids in keeping a constant pH. The high specific heat and mobility of water distribute heat uniformly throughout the body Water also helps in heat loss by convection and radiation from skin and plant surfaces High latent heat of evaporation of water causes elimination of excess heat through evaporation of sweat This maintains a *constant body temperature.* Elimination of waste products through urine also helps in homeostasis.

SUMMARY

Small molecules in the cells include carbohydrates such as monosaccharides, lipids, amino acids, nucleotides, minerals and water Polysaccharides, proteins and nucleic acids are macromolecules

Glucose is the main source of energy in cells and is the blood sugar of many animals It is utilised for the synthesis of lactose, glycogen, starch, fats and amino acids Ribose and deoxyribose are essential for the synthesis of nucleotides and nucleic acids Monosaccharides are polymerised into structural polysaccharides such as cellulose and oligosaccharides

Several kinds of lipids occur in cells Fats are esters of glycerol and long chain fatty acids Fats store an enormous amount of energy Unsaturated fats have lower melting points than saturated fats Phospholipids and glycolipids contain phosphate and carbohydrates respectively. The presence of both polar and nonpolar groups enables phospholipids to arrange themselves in lipid bilayers in aqueous medium Phospholipids, glycolipids and sterols (containing fused hydrocarbon rings and long hydrocarbon chain) are structural lipids and are components of membranes Steroid hormones and vitamin D are formed from sterols

Amino acids are carboxylic acids with an amino group. They are linked to form peptides. Amino acids polymerise into proteins They also participate in the formation of compounds such as glucose, histamine, certain animal hormones, melanin, heme and nicotinamide,

Nucleotides are complexes of a nitrogenous base, a pentose and one or more phosphate groups Purine and pyrimidine nucleotides polymerise to form DNA and RNA Higher nucleotides of purines and pyrimidines carry high-energy phosphate bonds in their molecules ADP and ATP provide ready energy for biological activities Nucleotides of nicotinamide and riboflavin function as coenzymes of some oxidising enzymes

Several minerals are essential for cells either for their structural framework or as components of biologically active molecules Salts of calcium and phosphorus are deposited in bones, teeth and exoskeleton to make them strong and hard

Sodium and potassium play important roles in the maintenance of fluid balance in cells and in the transmission of electrical impulses in nerve cells.

Magnesium is a constituent of chlorophyll It is required for the action of many enzymes Iron is an essential component of respiratory pigments such as hemoglobin and myoglobin Iodine is an essential part of the thyroid hormone Manganese is required for the action of many enzymes.

Water acts as a solvent for polar molecules The biologically active conformations of macromolecules and the arrangement of phospholipids in the lipid bilayer of membranes are dependent on water. Water provides the medium for chemical reactions. It also participates in many reactions by donating H^+ and OH^- Water helps to keep minerals ionised in body fluids. It also ionises itself to provide hydrogen ion(H^+) concentration to body fluids

QUESTIONS

1 Which of the following sets belongs to a distinct class or category?
  (a) ribose, sucrose, glucose, fructose
  (b) sterols, waxes, fatty acids, amino acids
  (c) oils, sterols, waxes, fats
  (d) nucleotide, nucleoside, nucleus, DNA

2 Distinguish between·
  (a) oligosaccharides and polysaccharides
  (b) saturated and unsaturated fatty acids
  (c) reducing sugars and non-reducing sugars
  (d) nucleotides and nucleosides

3 Match the item in column I with the appropriate item in Column II.

(a)

Column I	Column II
A Hexose	i saturated fat
B. ATP	ii. nucleoside
C Lactose	iii disaccharide
D Vanaspati	iv fructose
E Magnesium	v. chlorophyll
	vi. nucleotide

(b)

Column I	Column II
A Ribose	i sucrose
B Fructose	ii. cholesterol
C. Glycerol	iii nucleic acid
D Amino acid	iv. fatty acid
E Calcium	v protein
	vi exoskeleton.

4. Arrange the following carbohydrates in the order of increasing complexity of chemical structures. fructose, starch, oligosaccharide, maltose, triose

5 List the natural source and the constituent units of (a) sucrose, (b) lactose, (c) ATP, (d) fat.

6 What roles do lipids play in living organisms?

7. Account for the following
  (a) Salts dissolve in water,
  (b) Phospholipids form a thin layer on the surface of an aqueous medium,
  (c) Amino acids can be basic.

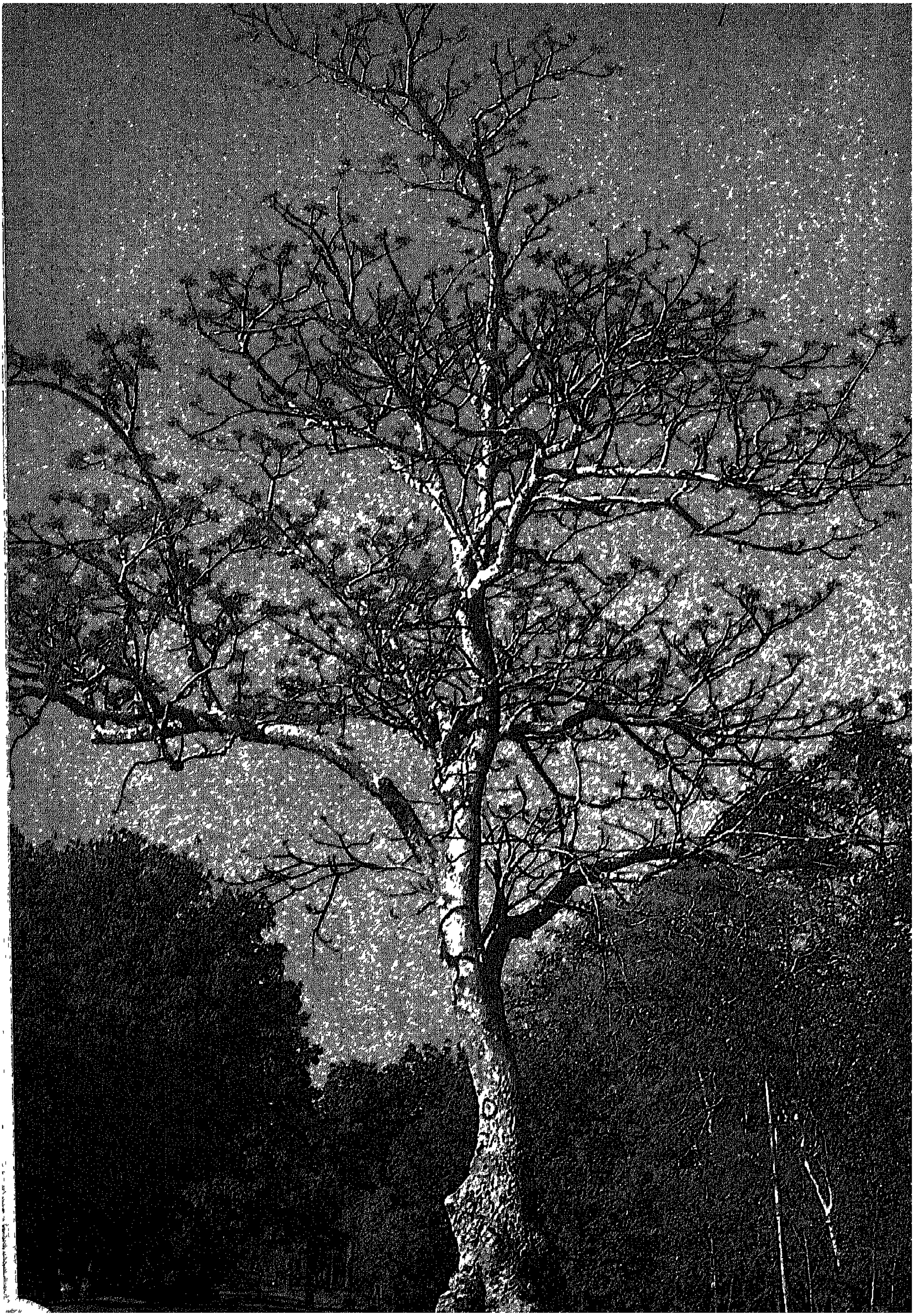
8 Oil does not dissolve in water Give a scientific explanation.

9 Mention the importance of the following minerals in organisms: magnesium, phosphorus, iodine, sodium, iron

10 Discuss the importance of water in the life of an organism.

11 What role do minerals play in maintaining the structure of animals?

12. What is the function of ATP in cell metabolism? Explain with the aid of a diagram how its structure makes this possible.



CHAPTER 6

CELLULAR MACROMOLECULES

IN the last chapter you learnt about small molecules such as sugars, amino acids and nucleotides. These polymerise to produce the large molecules, the macromolecules. Biologically, the most important macromolecules are the polysaccharides, proteins and nucleic acids These molecules have high molecular weights and may be branched or unbranched.

Polysaccharides

Polysaccharides are polymers of monosaccharides They are branched or unbranched linear molecular chains Starch, cellulose and glycogen are composed of a single type of monosaccharide, glucose (Fig. 6.1). Some others like agar are made up of more than one type of monosaccharides. Polysaccharides are grouped into two categories based on their functions

Food-Storage Polysaccharides

Starch is found abundantly in rice, wheat, and other cereal grains, legumes, potato, tapioca and bananas (Fig 6 2). It is formed during photosynthesis and serves as an energy-storing material. Glycogen found in liver and muscles stores energy in mammals. Storing carbohydrates in the form of polysaccharides has two advantages. During their formation many molecules of water are removed from monosaccharides. This helps in condensing the bulk to be stored. Unlike small carbohydrates, polysaccharides are relatively easy to store. When necessary polysaccharides are broken down by enzymes for the release of energy

Structural Polysaccharides

Cellulose is produced by plants and is used for building cell walls. Cellulose is the most abundant organic compound in the biosphere. Wood and cotton contain large quantities of cellulose. Cellulose is a fibrous polysaccharide and has high tensile strength. Chitin is a polysaccharide found in the exoskeletons of insects, crabs and prawns. Chitin is similar to cellulose in many ways except that its basic unit is not glucose, but a similar molecule that contains nitrogen (N-acetylglucosamine). Although chitin is soft and leathery, it becomes hard when impregnated with cal-

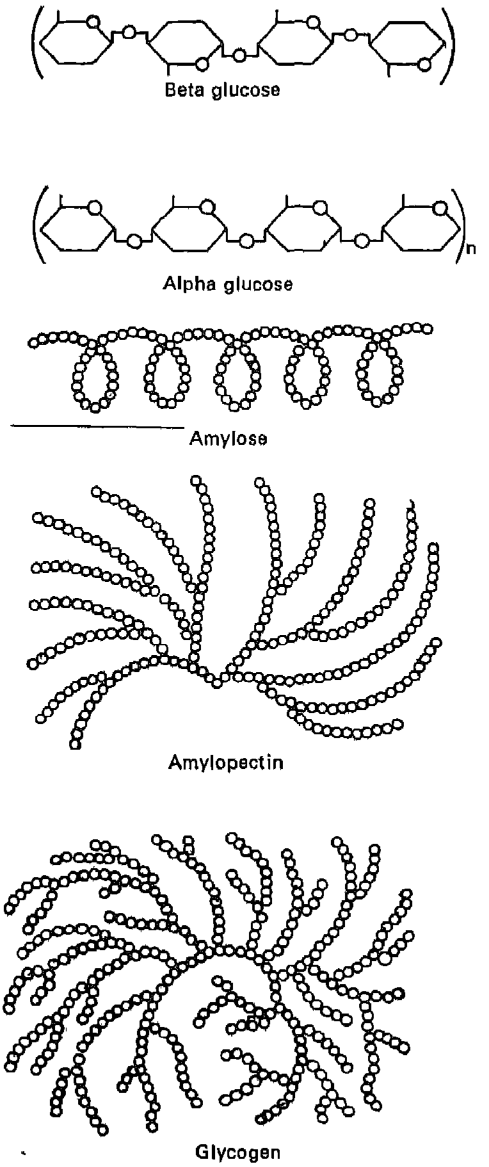


Fig. 6.1 Arrangement of glucose molecules in polysaccharides. Beta glucose is found in cellulose, alpha glucose in amylose, amylopectin and glycogen.

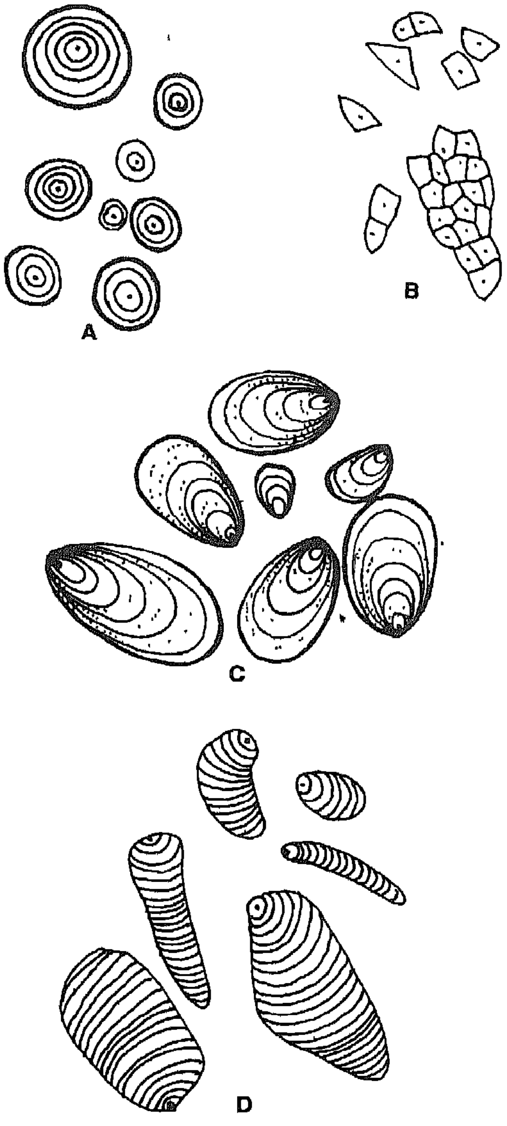


Fig. 6.2 Starch grains from (A) wheat, (B) rice, (C) potato and (D) banana

cium carbonate or certain proteins. The insolubility of these polysaccharides in water helps to retain the form and to strengthen the structure of organisms.

CELLULOSE

Cellulose is the main structural polysaccharide of plants. One molecule of cellulose has about 6000 glucose residues. Cotton fibres contain the largest amout (90 per cert) of cellulose among natural materials. Wood contains between 25 to 50 per cent cellulose, the rest being hemicellulose or lignin. Since time immemorial, man has used cellulose-containing materials for shelter, fuel, tools, etc Fibres of cotton, linen and jute are used for textile and ropes The artificial fibre RAYON is manufactured by dissolving cellulosic materials in alkali and by extruding and coagulating the filaments By treatment with other chemicals, cellulose is converted into CELLULOSE ACETATE (used in fabrics, cellulosic plastics and shatter-proof glass), CELLULOSE NITRATE (used in propellant explosives), and CARBOXYMETHYL CELLULOSE (added to ice creams, cosmetics and medicines to emulsify and give a smooth texture). Cellulose can be hydrolysed to soluble sugars Microbes can then convert these sugars to form ethanol, butanol, acetone, methane and other useful chemicals.

Cellulose forms the bulk and roughage in human food; necessary for the proper functioning of the digestive system. Human beings lack the enzyme required to digest cellulose. Some ruminants such as cow can digest cellulose because their stomach contains microorganisms that break down cellulose and make it digestible. Snails and termites also depend on microorganisms present in their gut to digest cellulose, which constitutes their major food.

MUCOPOLYSACCHARIDES Mucilages

The slimy substances produced by plants are called mucilages. When you soak the seeds of isabgol *(Plantago ovata)* or cut up the fruit of okra (bhindi), you will notice the presence of a slimy substance. Mucilages are polysaccharides formed from galactose and mannose. Many seaweeds yield mucilages such as agar, alginic acid and carrageenin which are of commercial value

Mucopolysaccharides are found in the cell walls of bacteria and in the connective tissues of animals, as well as in body fluids. These bind protein in cell walls and connective tissue, and water in interstitial spaces. These provide lubrication in ligaments and tendons The vitreous humor of the eye and synovial fluid also contain mucopolysaccharides. Hyaluronic acid is found in connective tissue and in cell walls. Keratin sulphate and chondriotin sulphate occur in cartilage, cornea and the skin, and impart strength and flexibility to them

Proteins

Proteins are among the most important macromolecules of organisms. When a Greek uses the word 'proteios', he refers to something of primary importance In the human body there are thousands of different kinds of proteins Proteins play varied roles Proteins serve to build cartilage and connective tissue, transport oxygen in blood and muscles, catalyse biological reactions as enzymes, defend the body against infections as antibodies, participate in body movement and as hormones control metabolism

Proteins are linear polymers of amino acids. In the protein molecule, many amino acids remain serially linked to each other by peptide bonds joining the amino and the carboxyl groups of successive amino acids The order in which amino acids occur is specific for a particular protein. The various permutations and combinations of the 20 amino acids allow for the synthesis of a large number of proteins.

The sequence of amino acids in polypeptide chain gives the protein its PRIMARY STRUCTURE. The primary structure, albeit very important, does not make a protein functional. To be functional the protein must have a particular 3-dimensional structure (conformation). A functional protein contains one or more polypeptide chains The sequence of amino acids in the chain determines where the chain will bend or fold, and where the various lengths will be attracted to each other Through the formation of hydrogen bonds peptide chains assume a SECONDARY STRUCTURE When a chain is arranged like a coil it is called an ∝ HELIX. When two or more chains are joined together by intermolecular hydrogen bonds, the structure is called the PLEATED SHEET (Fig. 6.3). Helical structure is found in keratin of hair and pleated structure in silk fibres.

In a large protein such as hemoglobin or an enzyme, further folds and coils are needed to attain the functional conformation. This is termed the TERTIARY STRUCTURE (Fig. 6 4). The coils and folds of the protein molecule are so arranged as to hide non-polar amino acid sidechains inside and expose the polar sidechains. The 3-dimensional conformation of a protein brings distant amino acid sidechains closer The active sites of proteins such as enzymes are thus formed. The conformation of proteins is easily changed by pH, temperature and chemical substances and hence the function of proteins is labile and subject to regulation

> In aqueous media proteins carry both cationic and anionic groups on the same molecule. The ionic state of the protein depends on the pH of the medium. A protein, rich in basic amino acids like lysine and arginine, exists as a cation and behaves as a base at the physiological pH of 7 4 (BASIC PROTEIN) e.g., histones of nucleoproteins. Similarly, a protein with acidic amino acids exists as an anion and behaves as an acid, e.g., most blood proteins (ACIDIC PROTEINS).

On the basis of structure, proteins are classified as simple or conjugated. SIMPLE PROTEINS are composed of amino acids only. Some are small, globular molecules mostly soluble in water and not coagulated by heat (e.g., histones) As the size of the protein molecule increases, it becomes less soluble and its heat-coagulability increases. For example, larger globular proteins (like egg albumin, serum globulins, and glutelins of wheat or rice) are coagulated by heat. Fibrous proteins have long molecules and

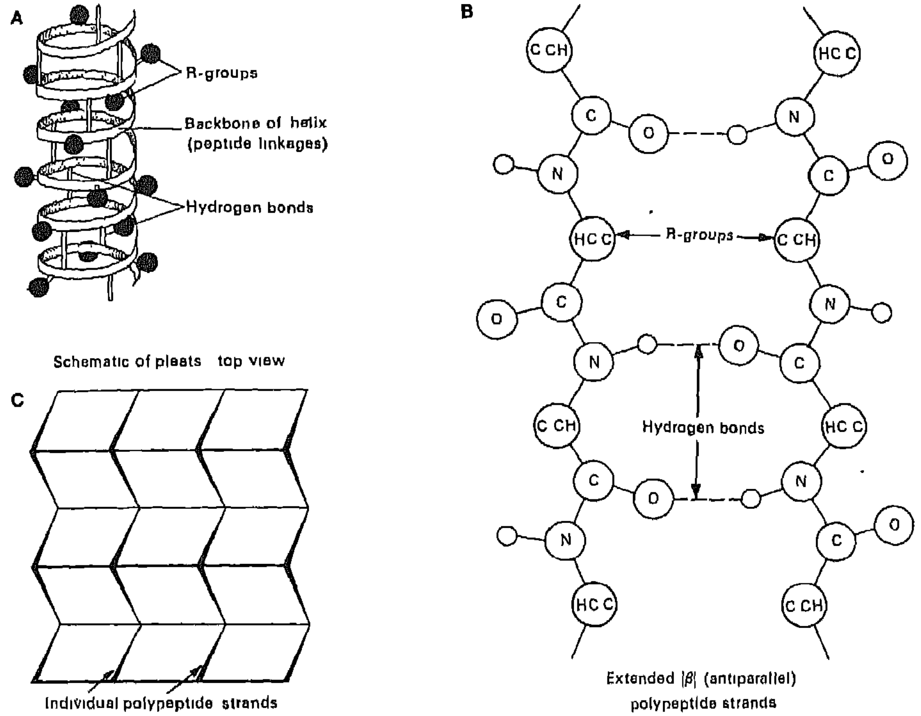

A
R-groups
Backbone of helix (peptide linkages)
Hydrogen bonds
B
C CH
HC C
C
O
N
R-groups
Hydrogen bonds
Extended |β| (antiparallel) polypeptide strands
Schematic of pleats top view
C
Individual polypeptide strands

Fig. 6.3 Secondary structure of proteins (A) arrangement of polypeptide chains in ∝-helix,(B), (C) β-pleated sheets

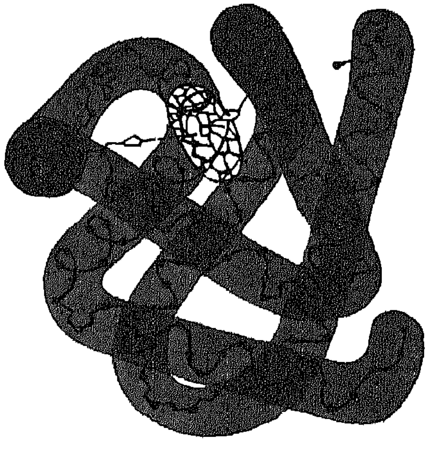


Fig 6 4 Tertiary structure of protein (myoglobin)

are insoluble in water (e.g., keratin of skin and hair, and collagen of connective tissues).

CONJUGATED PROTEINS are formed by the binding of a simple protein with a non-protein called the PROSTHETIC GROUP, (nucleoproteins have nucleic acids as prosthetic groups).

CLASSIFICATION OF CONJUGATED PROTEINS

Conjugated proteins are classified according to their prosthetic groups. Some examples are given below:

NUCLEOPROTEINS nucleic acid protein

complexes of chromosomes and ribosomes.

METTALOPROTEINS Metal-protein complexes (Fe-protein complex such as ferritin)

CHROMOPROTEINS pigment-protein complexes (hemoglobin and cytochromes)

PHOSPHOPROTEINS. Phosphate-protein complexes (casein of milk).

LIPOPROTEINS lipid-protein complexes occurring in membranes

GLYCOPROTEINS AND MUCOPROTEINS carbohydrate-protein complexes like mucin and some proteins of.the plasma membrane.

Functions of Proteins

Some proteins are essential structural components of cell membranes, organelles, cytoplasm, extracellular matrices and fibres Keratin is the major constituent of hair, skin, nails, horns, feathers and wool. Cartilage is made of collagen. In plants proteins are found in the walls of pollen grains

Many proteins function as ENZYMES to catalyse specific chemical reactions. Enzymes play a key role in the metabolism. The various aspects of enzymes are covered in the next chapter

Some proteins act as CARRIERS which bind and transport specific molecules across a membrane or in a body fluid. Hemoglobin (in blood) transports and myoglobin (in muscle) stores oxygen. In plants P-protein is involved in the transport of organic compounds through phloem. A number of proteins function as RECEPTOR MOLECULES These bind with specific informational molecules like hormones reaching the cell and mediate in their cellular effects HORMONES, such as insulin and parathyroid hormone, are proteins that regulate metabolism. CONTRACTILE PROTEINS like actin and myosin participate in cellular movements and locomotion. ANTIBODIES that participate in the defence mechanism of the body are also proteins. Storage proteins include albumin of egg and those that occur in seeds (glutelin of wheat).

Nucleic Acids

Nucleic acids are giant molecules having a variety of functions There are two major types DEOXYRIBONUCLEIC ACID or DNA and RIBONUCLEIC ACID or RNA, DNA is found mainly in the nucleus but also occurs in chloroplasts and mitochondria. It is the genetic material and contains all the information needed for the development and existence of an organism. RNA is produced mostly in the nucleus but moves out into the cytoplasm RNA is responsible for transmitting the information from the nucleus to the ribosomes where protein synthesis occurs. There are three types of RNA (1) RIBOSOMAL RNA or rRNA found in the ribosomes where protein synthesis occurs (2) MESSENGER RNA or mRNA which is produced in the nucleus and carries the information for the synthesis of proteins. For each protein there is a specific mRNA. (3) TRANSFER RNA or tRNA is a much smaller molecule than mRNA Its role is to collect amino acids from the cytoplasm for protein synthesis.

Nucleic acids are linear polymers of purine and pyrimidine nucleotides. The nucleotides are linked serially by phosphate groups, each linking the C^5 (5′-C) and the C^3 (3′-C) of the pentoses of the successive nucleotides (Fig. 6.5) The DNA molecule consists of a double chain of nucleotides, whereas RNA consists of a single chain The nucleotides of DNA contain the bases adenine (A), thymine (T), guanine (G) and cytosine (C). RNA contains A, G, C and

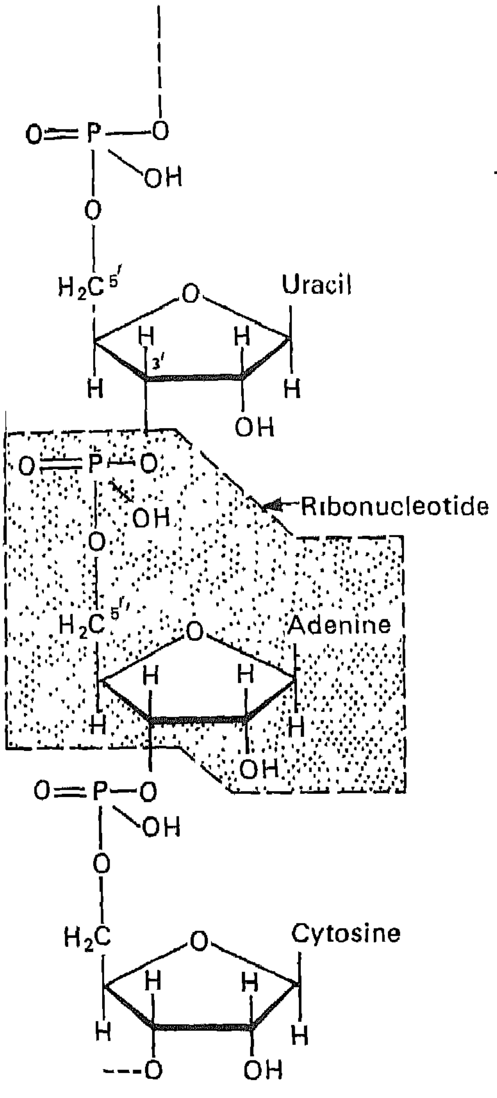


Fig. 6.5 A polynucleotide strand of RNA

uracil (U) instead of T. The backbone of the nucleic acid is uniformly made up of alternating pentose and phosphate groups. The pentose in DNA is deoxyribose ($C_5H_{10}O_4$) and that in RNA is ribose ($C_5H_{10}O_5$) The bases stick out from the backbone In the double stranded DNA the bases of the opposite strands pair in a [illegible] with C. This complementarity is known as the BASE-PAIRING RULE.

Each strand of DNA consists of thousands of interlinked deoxyribonucleotides (Fig. 6.6). One end of the strand is called its 5′ END. The last deoxyribonucleotide at that end has the 5′ – C of its deoxyribose free. The other end of the strand is called its 3′ END, because the 3′ – C of deoxyribose of the last nucleotide at that end is also free. In the DNA molecule the two strands are always ANTIPARALLEL to each other. That is, the 5′ end of each strand faces the 3′ end of the other

The double strand of DNA is coiled upon itself forming a double helix, like a spiral staircase with the sugar-phosphate units along the railing and the hydrogen-bonded base pairs as the steps. This is known as the WATSON AND CRICK MODEL of DNA (Fig. 6.6).

The DNA molecule is the most unique molecule in the living world. It is the only molecule that can replicate itself. All organisms contain DNA as the hereditary material. Certain animal and all plant viruses, however, have RNA as the hereditary material. Since the exact sequence of nucleotides is passed on from generation to generation, does it not intrigue you *that a portion of your DNA molecule* may be very similar to that of organisms that existed millions of years ago?

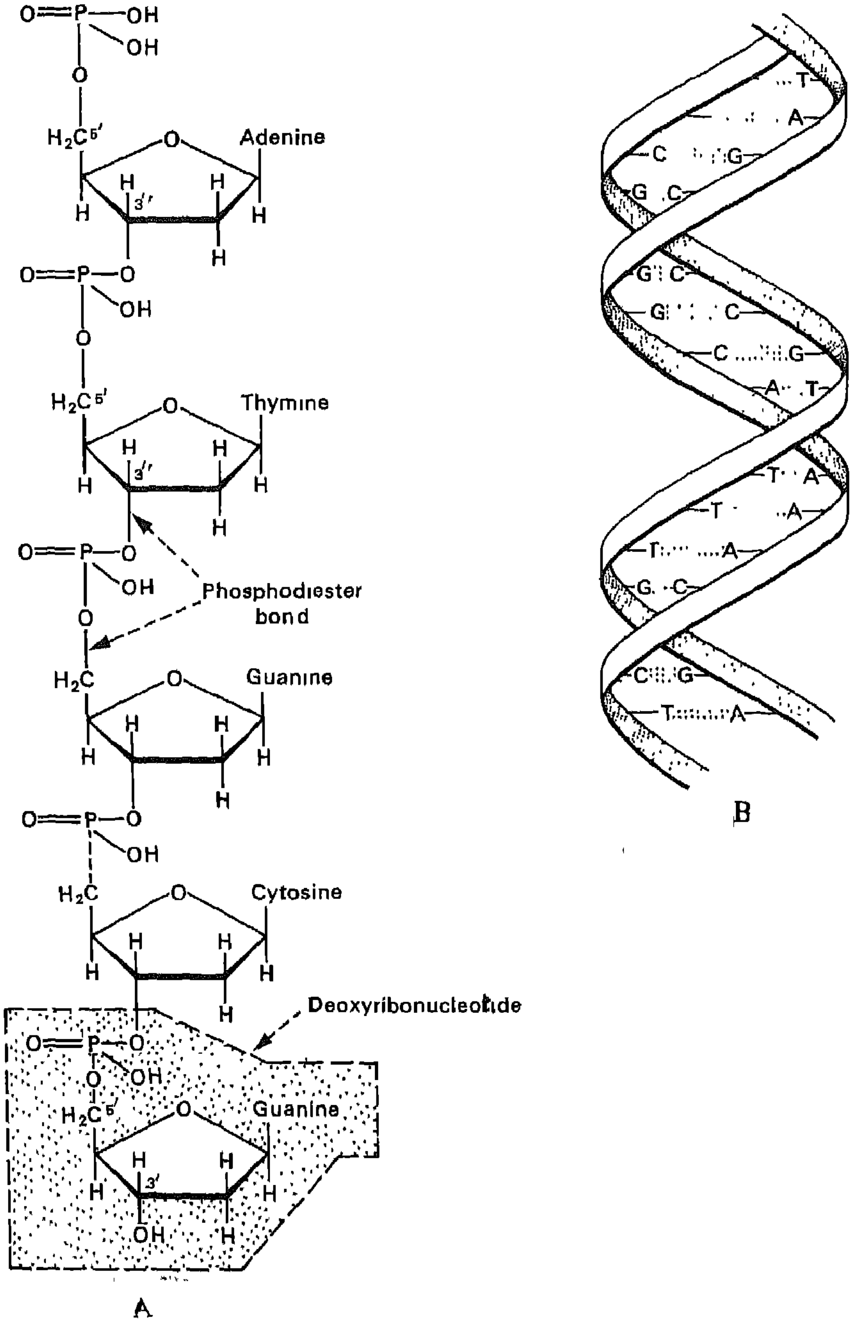


Fig. 6.6 (A) A polynucleotide strand of DNA
(B) Watson-Crick model of DNA double helix

SUMMARY

Cellular macromolecules consist of polysaccharides, proteins and nucleic acids. They are polymers of sugars, amino acids and nucleotides respectively They have high molecular weights, many ionic groups and both polar and non-polar groups Because of these, macromolecules assume specific 3-dimensional conformation in aqueous media Biological activities of these molecules depend on the 3-dimensional forms.

Polysaccharides are linear or branched polymers of monosaccharides of one or more types. Polysaccharides are the major products of photosynthesis. Food-polysaccharides, such as starch and glycogen, are stored in cells, and broken down to produce energy Others like cellulose are structural polysaccharides

Proteins are composed of amino acids Simple proteins are composed of amino acids only, whereas conjugated proteins have in addition a non-protein prosthetic group in the molecule

Each protein is composed of a peptide chain or chains, having a specific sequence of amino acids (primary structure) The peptide chains form helical coils or pleated sheets by hydrogen bonding (secondary structure) Depending on the sequence of polar and nonpolar amino acids, the protein molecule becomes folded or coiled in specific ways into 3-dimensional higher structures (tertiary structure) Only when a proper 3-dimensional structure is formed does the peptide chain become a functional protein molecule

Nucleic acids viz , deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are polymers of purine and pyrimidine nucleotides DNA molecules are composed of deoxyribonucleotides of adenine, guanine, cytosine and thymine The DNA molecule is a double helix of two coiled polynucleotide strands (Watson and Crick model) The two strands are antiparallel and are held together by hydrogen bonds between complementary purine and pyrimidine bases (base-pairing rule) DNA bears the hereditary characters which are passed on from generation to generation.

The RNA molecule is a single strand of ribonucleotides adenine, guanine, cytosine and uracil There are three types of RNA, ribosomal RNA or rRNA, messenger RNA or mRNA and transfer RNA or tRNA which play various roles in the synthesis of proteins.

QUESTIONS

1 Fill in the blanks:

(a) DNA has ________ instead of uracil

(b) rRNA is associated with ________

(c) Keratin is a ________ protein

(d) Double-helical structure is found in ________

(e) The carbohydrate molecule cellulose is a ________

(f) The double helix model of DNA was proposed by ________ and ________

(g) Hydrolysis of nucleic acids yields purine, sugar, ________ and ________

(h) ________ and ________ are storage polysaccharides

2 Observe the relationship between the first two words and then fill in a suitable word in the fourth place
   (a) amino acids : protein :: nucleotides : ______
   (b) plants : starch :: mammals : ______
   (c) ∝-helix protein double helix ______

3. Select the correct answer for each of the following
   (a) mRNA is a polymer of.
      (i) deoxyribonucleosides
      (ii) ribonucleosides
      (iii) deoxyribonucleotides
      (iv) ribonucleotides
   (b) The following is a storage protein
      (i) keratin
      (ii) collagen
      (iii) glutelin
      (iv) hemoglobin
   (c) The difference between RNA and DNA is because of
      (i) sugar and base
      (ii) sugar and phosphate
      (iii) phosphate and base
      (iv) Sugar only
   (d) The primary structure of a protein is due to:
      (i) hydrogen bonds
      (ii) peptide bonds
      (iii) -S-S linkages
      (iv) ionic bonds

4. List the nature source(s), monosaccharide units and function of the following polysaccharides, starch, glycogen and cellulose.

5 List four functions of proteins and name one protein that performs each function

6 Where do you find the following — in DNA, RNA or in both?
   (a) Ribose (b) Deoxyribose (c) Adenine (d) Uracil (e) Guanine.

7 Name one element invariably found in proteins but not in all carbohydrates and lipids Name another element which is generally present in proteins but not in all carbohydrates

8. Why are starch and glycogen more suitable than glucose as storage products?

9. Proteins have been called 'biological polymers.' Explain.

10 Although all proteins are made of the same amino acids, explain how your proteins may be different from those of a dog

11. Distinguish between the primary, secondary and tertiary structure of protein.

CHAPTER 7

ENZYMES

IN Chapter 4 we discussed how even within the microscopic dimensions of cells, special compartments carry out different functions You will be amazed to realise that over a thousand different reactions go on at any given time in a cell with an average diameter of 20 µm. How does the cell cope with such a bewildering array of chemical reactions, all of which need an initial input of energy, the ACTIVATION ENERGY, to start the reaction?

Sometimes a small amount of a substance significantly influences the rate of a chemical reaction The substance itself is not used up or changed at the end of the reaction Such a substance is called a CATALYST, and the phenomenon CATALYSIS The latter may be positive if the reaction rate is enhanced, or negative if the reaction rate is reduced. Both organic and inorganic substances can act as catalysts

Within the cell, the rate and efficiency with which the reactions go on depend on certain special molecules synthesised by the cells, the ENZYMES Enzymes are biological catalysts. The DNA in each cell has the necessary message (blue print) for the production of all the enzymes required by it. The cell uses this information as and when necessary to produce the enzymes required to catalyse specific reactions at any point of time.

Enzymes are synthesised by living cells. But they retain their catalytic action even when extracted from cells. Rennet tablets containing the enzyme rennin from the calf's stomach have long been used for coagulating milk protein to obtain casein (cheese from milk), for various uses, including the preparation of eatables.

DISCOVERY OF ENZYMES

Enzymes were discovered by accident. In 1897 a German chemist Edward Buchner was preparing yeast extract for medicinal purposes. The extracts he made invariably turned bad. He added some sugar to prevent spoilage. To his surprise the sugar fermented into alcohol. Pasteur had already demonstrated that living yeast cells promoted fermentation. Buchner discovered that living cells were not necessary but that yeast extract could bring about fermentation. The word 'enzyme' was coined. It literally means 'in yeast', but is now used as a general name for biocatalysts.

All enzymes are proteins but all proteins are not enzymes. Many enzymes contain a non-protein part called the PROSTHETIC GROUP. These are tightly bound to the enzyme. Some prosthetic groups are metal compounds. For example, iron-porphyrin complexes form the prosthetic groups of cytochromes. In addition, certain organic compounds and inorganic ions are required for enzyme activity. They are loosely bound to the enzyme and are called CO-FACTORS. Nucleotides of the vitamin nicotinamide (NAD) and riboflavin (FAD) are organic co-factors or COENZYMES of many oxidising enzymes of the mitochondria. In addition certain metals, especially those occurring in trace amounts, facilitate enzyme reaction. Iron (Fe^{++}) is a co-factor responsible for the catalytic action of catalase.

All enzymes have a specific three-dimensional structure, a part of which is known as the ACTIVE SITE. An enzyme may have more than one active site. The active site serves as a 'lock' into which the reactant (commonly referred to as the SUBSTRATE) fits in like a key (Fig. 7.1). The points where the substrate is bound on the active site is known as the substrate-binding site. Substrate binding causes a lowering of the activation energy and allows the reaction to proceed (Fig. 7.2). Once the reaction is completed the enzyme releases the PRODUCTS and is ready to catalyse again. How fast do enzymes act? A single molecule of the enzyme carbonic anhydrase, the fastest enzyme known, hydrates 36 million (36×10^6) molecules of carbon dioxide per minute.

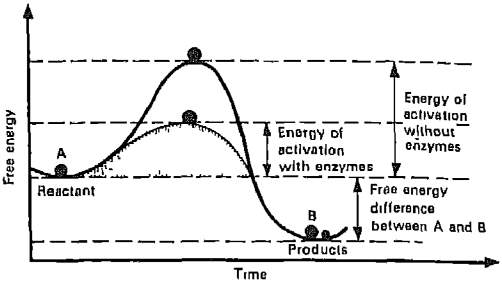


Fig. 7.2 Activation energy requirement of non-catalysed and enzyme-catalysed reactions

$$CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} H_2CO_3$$

The catalysed reaction is 10 million (10^7) times faster than the non-catalysed reaction.

Let us now examine the similarities and differences between inorganic catalysts and enzymes.

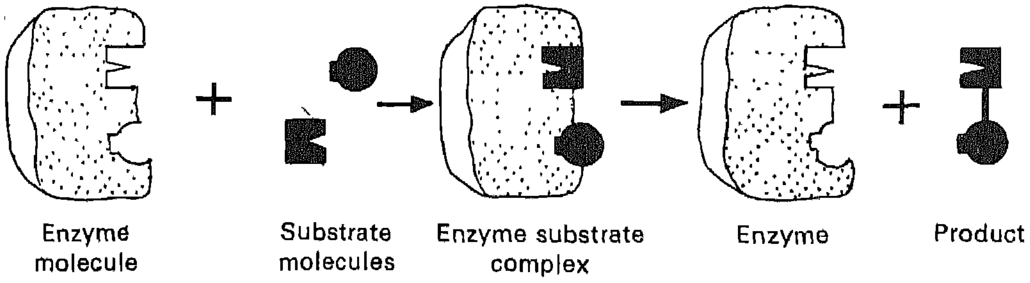


Fig. 7.1 'Lock and Key' hypothesis of enzyme action

Activity Take 2 ml of hydrogen peroxide (H_2O_2)solution in two test tubes. Add a pinch of manganese dioxide (MnO_2) powder to one and a small piece of fresh liver or potato to the other Keep the test tubes at room temperature in summer or in a beaker of warm water (at 38°C) in winter. Bubbles of oxygen evolve in the two test tubes Thus both manganese dioxide and a tissue enzyme (peroxidase or catalase) can catalyse the evolution of oxygen from hydrogen peroxide Repeat the same experiment, but use boiled and cooled manganese dioxide suspension and a boiled and cooled liver/potato slice Gas evolution still occurs in the hydrodgen peroxide solution treated with boiled and cooled manganese dioxide But the tube containing the boiled tissue slices does not evolve oxygen This experiment demonstrates that heat inactivates the enzyme but not the inorganic catalyst

Similarities between Inorganic Catalysts and Enzymes

1 Inorganic catalysts and enzymes remain unchanged after reaction, chemically and quantitatively, and can be used over and over again

2 Both are required in minute quantities compared to the substrate

3 They do not alter the equilibrium of a reversible reaction.

4. They do not initiate a reaction, but only enhance its rate by lowring the activation energy.

5. They form short-lived complexes with the reactants.

Dissimilarities between Inorganic Catalysts and Enzymes

Inorganic Catalysts	*Enzymes*
1. Small molecules or simple mineral ions	1. Proteins with complex three-dimensional structure
2 Can catalyse diverse reactions	2. Catalyse only specific reactions of a single or only a few substrates.
3. Not regulated by any regulator molecules	3. Can be regulated by specific molecules which can change conformation and therefore activity
4. Are less sensitive to temperature and pH.	4. Are more sensitive to changes in temperature and pH.

Classification of Enzymes

Enzymes were variously named in the past. Enzymes, such as ptyalin (salivary amylase), pepsin and trypsin, give no indication of their action. Other enzymes such as amylase, sucrase, protease and lipase, were named after the substrates on which they acted—amylose (starch), sucrose, protein and lipids respectively. Still others were named according to the source from which they were obtained—papain from papaya, bromelain from pineapple (beisomer

longs to the family Bromeliaceae) Some like DNA polymerase indicate its specific action, polymerisation. To facilitate scientific communication and to maintain uniformity, enzymes are now categorised and named by an international code of enzyme nomenclature

The name of each enzyme ends with an *ase* and consists of two parts. The first part indicates its substrates and the second the reaction catalysed For example, glutamate pyruvate transaminase transfers an amino group from the substrate glutamate to another substrate pyruvate. However, arbitrary names like ptyalin and trypsin still continue to be used because of their familiarity

Enzymes are grouped into six major classes.

Class 1 Oxidoreductases: These catalyse oxidation or reduction of their substrates and act by removing or adding electrons (and/or H⁺) from or to substrates e.g., cytochrome oxidase oxidises cytochrome.

Class 2. Transferases· These transfer specific groups from one substrate to another. The chemical group transferred in the process is not in a free state, e.g , glutamate pyruvate transaminase

Class 3. Hydrolases· These break down large molecules into smaller ones by the introduction of water (hydrolysis) and breaking of specific covalent bonds. Most digestive enzymes belong to this category, e g , amylase which hydrolyses starch.

Class 4 Lyases· These catalyse the cleavage of specific covalent bonds and removal of groups without hydrolysis, e.g , histidine decarboxylase cleaves C — C bond in histidine to form carbon dioxide and histamine.

Class 5 Isomerases These catalyse the rearrangement of molecular structure to form isomers, e g , phosphohexose isomerase changes glucose-6-phosphate to fructose-6-phosphate (both are hexose phosphates)

Class 6 Ligases· These catalyse covalent bonding of two substrates to form a large molecule. The energy for the reaction is derived from the hydrolysis of ATP Pyruvate carboxylase combines pyruvate and carbon dioxide to form oxaloacetate at the expense of ATP.

Covlant bond large moh

Properties of Enzymes

(a) Specificity Each enzyme can catalyse the change of either a specific substrate or a specific group of substrates only The specificity for a substrate may easily be demonstrated in the following way·

Activity: Take 3 ml of Benedict's solution containing cupric sulphate, in two test tubes. 1 ml of starch solution (1%) is added to one and 1 ml of sucrose solution (1%) to the other. The solutions are then boiled for a couple of minutes. No change occurs in either of the test tubes. So, both starch and sucrose are non-reducing carbohydrates Neither of them can reduce Cu^{++} of the reagent to Cu^{+} Next, saliva is collected in two fresh test tubes Starch is added to one of them and sucrose to the other Both test tubes are kept at room temperature in summer for about one hour, and in warm water (about 38°C) in winter. Benedict's solution is then added to both test tubes and their contents are boiled for a couple of minutes The blue solution changes to yellow or red precipitate in the test tube containing starch This indicates that the enzyme salivary amylase hydrolyses starch to reducing sugars The latter reduces Cu^{++} to Cu^{+} which forms the coloured precipitate of cuprous oxide (Cu_2O). But the test tube containing sucrose shows no change. Thus, salivary amylase cannot hydrolyse sucrose. No reducing sugar is produced and the colour of Benedict's solution remains unchanged.

(b) Optimum Temperature Enzymes generally work over a narrow range of temperatures. Usually it corresponds to the body temperature of the organism For instance, human enzymes work at the normal body temperature. Each enzyme shows its highest activity at a particular temperature. This is called the optimum temperature. Activity declines both above and below the optimum temperature Cold preserves the enzyme in a temporarily inactive state. Food may be preserved for long in a frozen state because neither microbial enzymes nor enzymes in the food can act at low temperatures to cause its spoilage. As demonstrated earlier, very high temperatures destroy enzyme activity. This is because proteins are denatured by heat For this reason, few cells can tolerate temperatures above 45°C. Some heat resistant species like microorganisms living in hot springs at temperatures close to 100°C, possess heat-resistant enzymes

(c) Optimum pH: Each enzyme shows its highest activity at a specific pH. This is called the optimum pH. Activity declines both above and below the optimum pH. Most intracellular enzymes function best around neutral pH Some digestive enzymes have their optimum in the acidic or alkaline range For example, the protein digesting enzyme pepsin found in the stomach, has an optimum pH of 2.0. Another protein-digesting enzyme, trypsin, found in the duodenum, functions best in an alkaline pH of 8.5.

Activity Take 2 ml starch solution (1%) in two test tubes Some saliva is collected and mixed with the contents of each tube. A few drops of dilute hydrochloric acid are added to one of the tubes. Both test tubes are then kept for one hour at room temperature in summer or in beaker containing warm water (about 38°C) in winter. Subsequently a drop of dilute iodine solution is added to each tube In the test tube whose contents were acidified, a blue colour develops, due to the reaction of unchanged starch with iodine. But the content of the other test tube is not coloured blue with iodine, indicating that starch has been hydrolysed by salivary amylase. This shows that amylase hydrolyses starch at salivary pH, but fails to act at a more acid pH.

In the stomach, salivary amylase swallowed with food is inactivated by the hydrochloric acid present in the gastric juice

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Pepsin is secreted in an inactive form called pepsinogen Inactive pepsinogen is hydrolysed to active pepsin in the stomach by either gastric hydrochloric acid or pre-existing pepsin

(d) [illegible]
enzy[illegible]
site on the active site in its molecule. A highly reactive enzyme-substrate complex is consequently produced. The latter almost

immediately dissociates into the product or products (P) and the unchanged enzyme

$$E + S \rightleftharpoons \underset{\text{short-lived}}{ES} \rightarrow EP \rightarrow E + P$$

Formation of the enzyme-substrate complex is essential for catalysis. The higher the affinity of the enzyme for its substrate, the greater is its catalytic activity

(c) Effect of Substrate Concentration: With the increase in substrate concentration (S), the velocity V of the enzymatic reaction rises at first. But the rise in V decreases progressively with the rise in (S) The reaction ultimately reaches a maximum velocity, which is not exceeded by any further rise in substrate concentration (Fig. 7 3). This happens because enzyme molecules are fewer than the substrate molecules Any more increase in substrate concentration will saturate all the enzyme molecules. No enzyme is left free to bind with additional molecules of the substrate

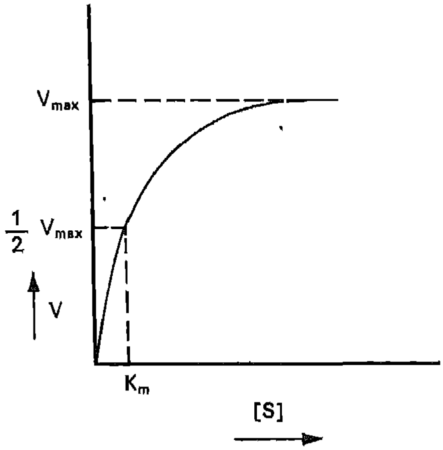


Fig. 7.3 Effect of substrate concentration on the velocity of enzymatic reaction V max, maximum velocity

Michaelis constant (Km) of an enzyme is the substrate concentration at which the reaction attains half its maximum velocity (Fig 7 3). It is a measure of the affinity of the enzyme for its substrate The lower the Km, the higher is the substrate affinity of the enzyme. An enzyme possesses different affinities for different substrates. So, its Km value differs from substrate to substrate. Proteases can act on a variety of proteins. The Km value of the protease will vary with the type of protein

Inhibition of Enzyme Action

Enzyme action can be inhibited in four different ways Inhibition of enzyme action by denaturation of proteins has already been mentioned. The other three ways in which enzymes can be inhibited are:

(a) Competitive Inhibition The action of an enzyme may be reduced or inhibited in the presence of a substance that closely resembles the substrate in molecular structure. Such an inhibitor is called a COMPETITIVE INHIBITOR of that enzyme Due to its close structural similarity with the substrate, the inhibitor competes with the latter for the substrate-binding site of the enzyme (Fig. 7.4). Consequently, the enzyme cannot participate in catalysing the change of the substrate. As a result the enzyme action declines, e.g , the inhibition of succinate dehydrogenase by malonate, which closely resembles succinate in structure This may be compared to a lock jammed by a key similar to the original key. Such competitive inhibitors are often used in the control of bacterial pathogens For instance, sulpha drugs are competitive inhibitors of folic acid synthesis in bacteria as they substitute for p-amino benzoic acid, thus preventing the next step in the synthesis.

(b) Non-competitive Inhibition: Cyanide kills an animal by inhibiting cytochrome

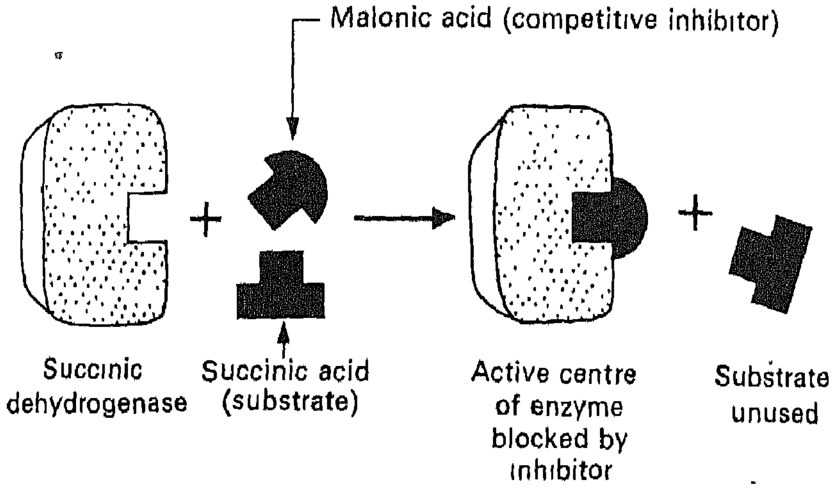

Malonic acid (competitive inhibitor)
Succinic dehydrogenase
Succinic acid (substrate)
Active centre of enzyme blocked by inhibitor
Substrate unused

Fig. 7.4 Competitive inhibition of enzyme action

oxidase, a mitochondrial enzyme essential for cellular respiration This is an example of non-competitive inhibition of an enzyme. Here the inhibitor (cyanide) has no structural similarity with the substrate (cytochrome c) and does not bind with the substrate-binding site but at some other site of the enzyme Thus in non-competitive inhibition substrate binding takes place but no products are formed.

(c) Allosteric Modulation or Feedback Inhibition. The activities of some enzymes, particularly those which form a part of a chain of reactions (metabolic pathway), are regulated internally. Some specific low molecular weight substance, such as the product(s) of another enzyme further on in the chain, acts as the inhibitor. Such a modulator substance binds with a specific site of the enzyme different from its substrate-binding site This binding increases or decreases the enzyme action. Such enzymes are called ALLOSTERIC ENZYMES; e.g , hexokinase which changes glucose to glucose-6-phosphate in glycolysis.Decline in enzyme activity by the allosteric effect of the product is called FEEDBACK INHIBITION, e g , allosteric inhibition of hexokinase by glucose-6-phosphate (Fig. 7.5).

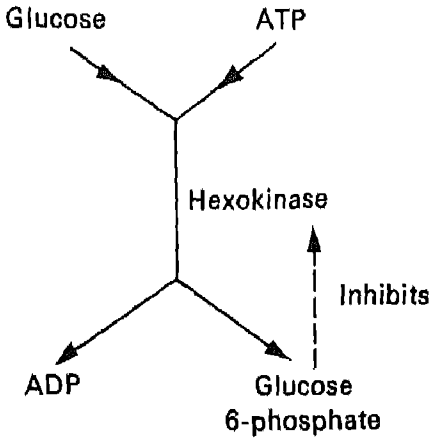


Fig. 7.5 Feedback allosteric inhibition

SUMMARY

The living world can sustain its busy pace entirely because of the presence of enzymes Enzymes, the bio-catalysts synthesised in living cells, are proteins Some have a non-protein part called the prosthetic group or coenzyme Many require the presence of co-factors like mineral ions to function. According to the nature of reactions catalysed, enzymes are classified into oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases

Enzymes are required in minute amounts and are not used up or changed at the end of a reaction They accelerate the rate of a reaction by reducing the energy required for it Reactions catalysed by enzymes are often a million times faster than the non-catalysed ones.

The three-dimensional form of enzymes makes the enzyme more versatile than inorganic catalysts. Generally an enzyme acts on some specific substrates Every enzyme acts best at optimum pH and at optimum temperature. High temperature may permanently destroy enzyme action Cold preserves the enzyme in a temporarily inactive state. Enzyme activity is also controlled by substrate concentration The substrate binds with a specific site of the enzyme The highly reactive enzyme-substrate complex almost immediately dissociates to give the product and the unchanged enzymes

Sometimes a substance which structurally resembles the substrate, inhibits the enzyme by occupying its substrate-binding site This is called competitive inhibtion. Non-competitive inhibition results from the interaction with a substance which is not structurally similar to the substrate. Allosteric modulation or feedback inhibition is due to inhibition of enzyme action by the product(s) of the reaction.

QUESTIONS

1 Fill in the blanks with suitable words
   (a) Biochemical reactions are regulated by catalysts called __________.
   (b) A vitamin is often associated as a __________ with an enzyme
   (c) The molecules on which enzymes act are known as __________.
   (d) Enzymes which breakdown compounds without the involvement of water are called__________.
   (e) A compound with almost similar structure to the substrate can act as a__________ __________.

2. Tick (√) the correct answer in each of the following:
   (a) Coenzyme is
      (i) always a protein
      (ii) often a metal
      (iii) always an inorganic compound
      (iv) often a vitamin

(b) Enzymes generally have
  (i) same pH and temperature optima
  (ii) same pH but different temperature optima
  (iii) different pH but same temperature optima
  (iv) different pH and different temperature optima

(c) The term feed-back refers to
  (i) the effect of substrate on the rate of enzymatic reaction
  (ii) the effect of end product on the rate of enzymatic reaction
  (iii) the effect of enzyme concentration on its rate of reaction
  (iv) the effect of an external compound on the rate of enzymatic reaction

(d) Which of the following is the best evidence for the lock and key theory of enzyme action?
  (i) All isolated enzymes have been identified as proteins.
  (ii) Compounds similar in structure to the substrate inhibit the reaction
  (iii) Enzymes are found in living organisms and speed up certain reactions
  (iv) Enzymes determine the direction of a reaction

3 What kind of reaction does each of the following group of enzymes catalyse?
(a) hydrolases (b) dehydrogenases (c) lyases (d) transferases

4 What is the name given to that part of the enzyme where catalytic work is carried out?

5 How does competitive inhibition of an enzyme occur?
How is such inhibiton useful?

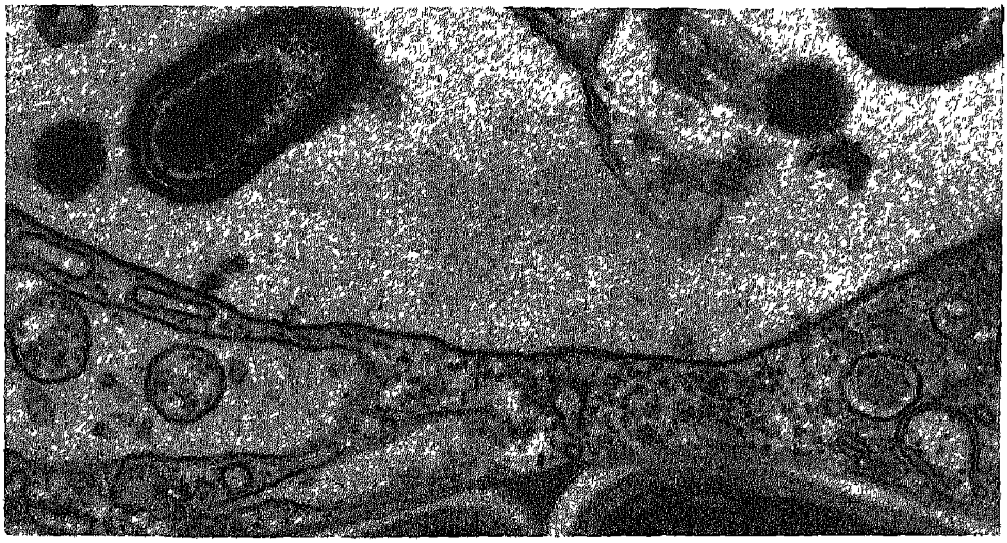
6 How does competitive inhibition differ from allosteric inhibition?

7 What does an enzyme do in terms of energy requirement of a reaction? What would happen if the enzyme did not play this role?

8. List three important properties of enzymes.

9. How are enzymes named? How have enzymes been classified recently?

10. What role does temperature play in food preservation? explain



CHAPTER 8

CELL MEMBRANES

YOU will recall that all cells are enclosed by a thin, film-like, pliable membrane called the PLASMA MEMBRANE or PLASMALEMMA. In addition, a eucaryotic cell also possesses intracellular membranes that surround the vacuole and organelles. The plasma membrane and the subcellular membranes are grouped together as BIOLOGICAL MEMBRANES.

The membranes, as you are aware, compartmentalise the cells They do not, however, totally isolate the contents of a compartment from surrounding compartments or media There is a continuous flow of materials and information across the membrane Membranes are permeable to some substances to different degrees and impermeable to others (SELECTIVE PERMEABILITY) CARRIER MOLECULES also occur in membranes. These molecules bind with and transport specific materials in specific directions across the membranes Thus membranes provide for selective exchanges between compartments Consequently, they help to maintain different distribution of molecules in adjoining compartments

The quasi-fluid state of membranes enable them to undergo DYNAMIC CHANGES. They are continually renewed, removed, extended, folded and moved. Consequently, continuous changes occur in their form, size and functions.

Unit Membrane Concept

As biological membranes are very thin and difficult to see, much of the early information on their structure came from indirect approaches based on their physico-chemical properties. In the late 1930s Danielli and Davson had proposed that the plasma membrane is made up of lipid sandwiched between two continuous layers of protein. The lipid molecules are set at right angles to the surface. With the development of the electron microscope, it became possible to understand the internal structure of membranes. Under the electron microscope all biological membranes reveal three layers, viz., two dark outer layers (electron dense) separated by a lighter middle layer These correspond to two outer layers of

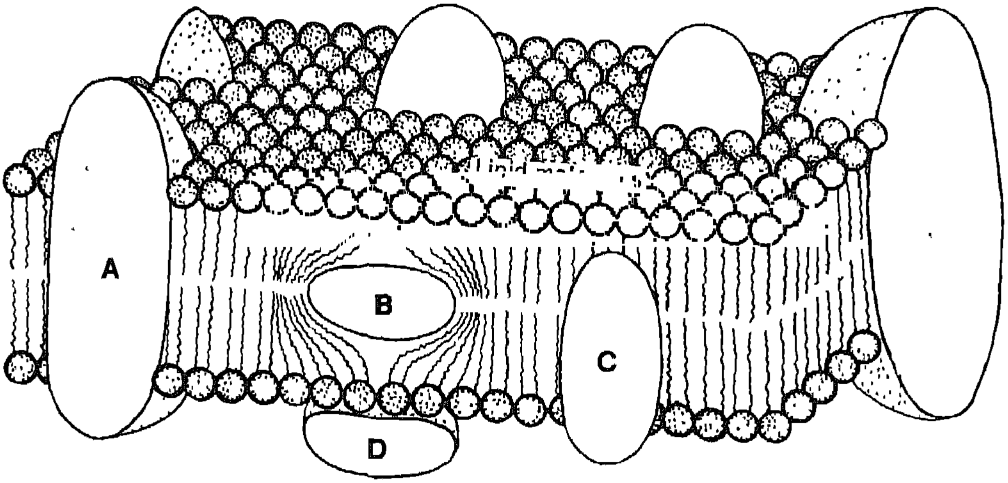


Fig 8.1 Fluid mosaic model of membrane structure. A,B and C are integral proteins and D is a peripheral protein.

proteins and a middle layer of phospholipids Because of this, it is called the UNIT MEMBRANE.

The plasma membrane and organelle membranes perform similar functions as a result of their basic structural similarities In spite of these similarities, different membranes show many structural, physico-chemical and functional differences. For instance, the proportion of lipids to proteins varies from 1 0 8 to 1:4. So, the unit membrane concept cannot be applied without reservations.

Fluid Mosaic Model

An analysis of all the known facts about membranes led Singer and Nicholson in the early 1970s to propose the 'Fluid Mosaic Model' (Fig 8.1). This model also visualises a central bilipid layer composed of phospholipids, with their spherical, polar head groups on the outer surfaces. The two non-polar tails of each molecule point inwards This arrangement forms a water resistant barrier, through which only lipid soluble substances can pass. (Recall from Chapter 5 that the polar heads are hydrophilic and the non-polar tails are hydrophobic).

Activity : To show the presence and importance of membrane lipids, beet root slices are placed in benzene After about half an hour the root slices are taken out from benzene They are wiped between filter papers to remove benzene from their surfaces. The root slices are next placed in water for 1/2 hour. The water soon turns red, indicating the outflow of water-soluble pigments from the root cells. If beet root slices untreated with benzene are placed in water, the latter does not become coloured. Evidently, the plasma membrane and tonoplast which retain the pigments in the cell are made of lipids Benzene dissolves membrane lipids to permit pigment to flow out of the cells.

Proteins are either embedded in the lipid layer (INTEGRAL PROTEINS) or superficially attached (PERIPHERAL PROTEINS). The latter can be easily dislodged from the membrane However, to obtain integral proteins the membrane has to be disrupted

Some large, globular integral proteins, which project beyond the lipid layer on both sides, are believed to have channels through which water-soluble materials can pass Some smaller integral proteins partially penetrate the lipid bilayer and are exposed on one surface only.

Some membrane lipids and integral proteins remain bound to oligosaccharides. Such oligosaccharides project into the extracellular fluid from the outer surface of the plasma membrane. They influence the manner in which cells interact with one another. Cells apparently recognise one another on the basis of these glycoproteins and glycolipids Experiements have been set up to demonstrate the remarkable ability of cells to recognise one another. In one such experiment cells from different tissues were mixed and allowed to grow on nutrient medium. The cells gradually moved about until each had found its own type. The result was distinct clusters of specific tissue types The capacity of cell membranes to recognise their own kind plays a distinct role in blood-grouping, immune response, cancer and rejection of transplanted organs.

There are specific proteins in the membrane, MEMBRANE RECEPTORS, which mediate in the flow of materials and information into the cell, by binding with specific molecules reaching the cell surface. For example, some receptors bind with hormones such as adrenaline.

Some membrane proteins function as enzymes. Each membrane carries an assortment of enzymes according to its functions The mitochondrial membrane, for example, carries electron transport enzymes which participate in respiration.

The fluid mosaic model was described by its authors as "protein icebergs in a sea of lipids." The fluidity of the membrane has been demonstrated in a number of original but simple experiments (Fig. 8.2). Two different cells were labelled, one with a red fluorescent dye and the other with a green dye. The two cells were then fused The fused cell was viewed immediately under the microscope. One half was observed to be green and the other half red After some time at 37°C, however, it was seen that the red and green dyes were thoroughly mixed. This could happen only if the lipid layer was fluid and the labelled proteins could move about in it Further proof of the fluidity of the lipid membrane came from the fact that such fused cells, if kept immediately at 0°C, failed to show mixing of colours. Lipids tend to solidify at low temperatures and hence the fluidity was lost Fluidity was restored as soon as the temperature was raised to 37°C, allowing mixing of dyes.

Membrane Transport

Membranes form physical boundaries between organelles and cytoplasm, and between the cell and extracellular fluids. They are SELECTIVELY PERMEABLE. Materials are transferred across the membrane either by passive physical processes such as diffusion and osmosis or by active transport

(a) *Passive Transport.* This type of transport requires neither activity nor energy expenditure by the cell

(i) *Diffusion* results from continuous random movements of solute or gas particles. The net diffusion of a substance occurs always from a region of its high concentration to a region of its low concentration, i.e , down its own CONCENTRATION GRADIENT Such movements enable the parti-

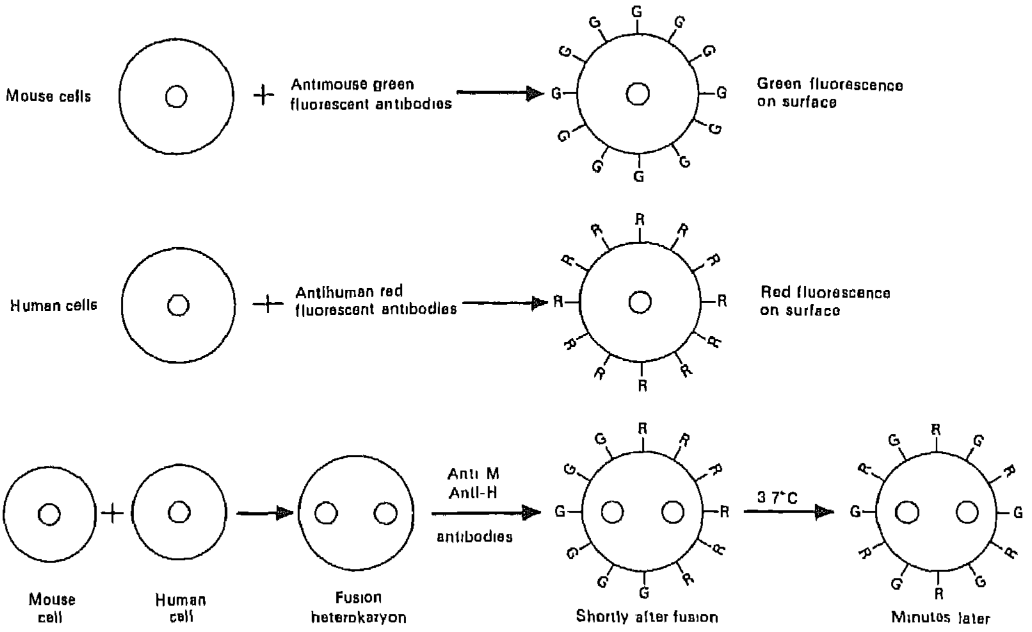

Mouse cells
Antimouse green fluorescent antibodies
Green fluorescence on surface
Human cells
Antihuman red fluorescent antibodies
Red fluorescence on surface
Mouse cell
Human cell
Fusion heterokaryon
Anti M
Anti-H
antibodies
Shortly after fusion
37°C
Minutes later
G
R

Fig. 8.2 Experiment demonstrating fluidity of plasma membrane

cles to cross a membrane permeable to them When copper sulphate crystals are placed in a beaker of water, in a short while the water just surrounding them turns blue The colour then spreads progressively, until all the water turns uniformly blue. Evidently, the dissolved copper sulphate diffuses from an area of high concentration to a lower one, until it attains an identical concentration in the entire volume of water (Fig 8.3)

Many water-soluble solutes and ions such as K^+, Cl^- and HCO_3^- diffuse through water-filled pores in the membrane For this, the pore diameter must exceed the diameters of the diffusing particles. An ion diffuses from the side richer in like charges or analogous ions to the side with an excess of opposite charges or COUNTERIONS. This difference of electrical charges between two sides of a membrane is called an ELECTRICAL GRADIENT. For example,

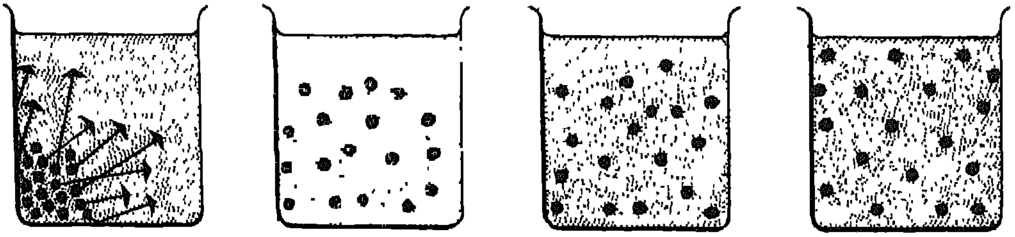


Fig 8.3 Diagrammatic representation of diffusion of copper sulphate in a beaker of water

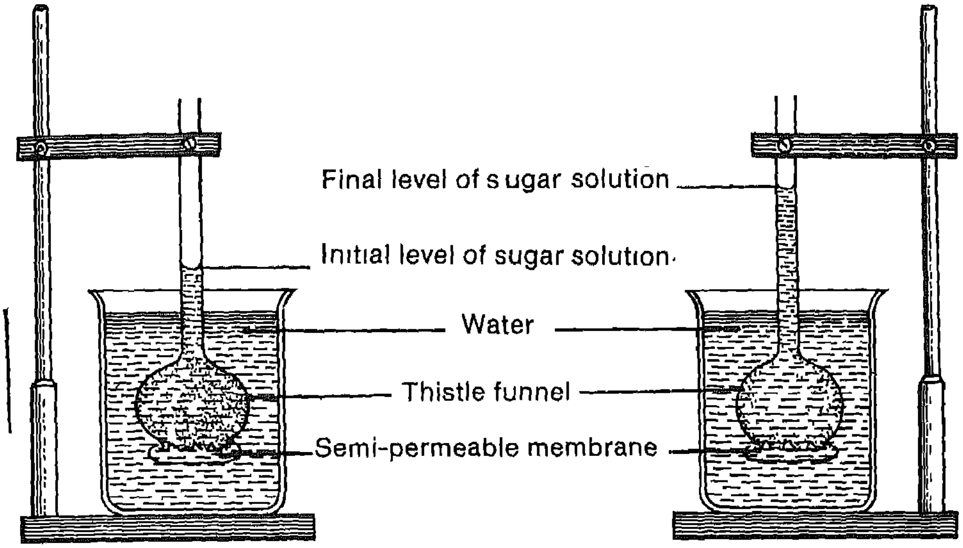

Final level of sugar solution
Initial level of sugar solution
Water
Thistle funnel
Semi-permeable membrane

Fig. 8.4 Osmosis

K^+ diffuses from the more electropositive side of the membrane to the more electronegative side. In effect, an ion diffuses down its ELECTROCHEMICAL GRADIENT; the resultant of its concentration and electrical gradients.

The net diffusion of a gas always occurs down its pressure gradient. If two gas mixtures are separated by a permeable membrane, each gas diffuses from the side with its higher partial pressure to that with its lower partial pressure. In cellular respiration, oxygen diffuses into the cell from the extracellular fluid, because its partial pressure is higher in the extracellular fluid than in the cell Carbon dioxide diffuses out from the cell because its partial pressure is higher there than in the extracellular fluid.

(ii) *Osmosis* is a process by which solvent molecules migrate across a semi-permeable membrane, from a region of low solute concentration to a region of high solute concentration In organisms the solvent is invariably water Movement of water from a region of its high concentration to its region of lower concentration tends to equalise the solute concentration on the two sides of a cell membrane.

Osmosis may be demonstrated by using an animal membrane like a fish bladder membrane or egg membrane, impermeable to sucrose but permeable to water The membrane is tied over the mouth of the thistle funnel having a long stem The funnel is then inverted, partially filled with a concentrated sugar solution and dipped in distilled water in a beaker (Fig 8 4) The level rises in the stem of the funnel due to the entry of water by osmosis The water continues to rise in the thistle funnel, till the hydrostatic pressure exerted by the column prevents further entry of the water molecules. This happens in spite of concentration difference existing between the two sides of the membrane. The hydrostatic pressure which balances and prevents the osmotic inflow of water into the concentrated solution, is called OSMOTIC PRES-

SURE. When this stage is reached, water molecules move equally in both direction.

Thus, osmotic pressure of a solution is that difference in hydrostatic pressure between it and the pure solvent, which stops the osmotic flow of water from the solvent to the solution across a semipermeable membrane. The more concentrated a solution, the higher its osmotic pressure

The external osmotic environment of a cell is described in terms of its TONICITY. When the relative concentration of water and solutes on either side of the cell membrane is the same, the solution is called ISOTONIC. In such a solution there is no net movement of water molecules across the membrane. 0.9 per cent sodium chloride and 5 per cent glucose are isotonic for human erythrocytes Solutions that have lower solute concentration than intracellular fluids (cytoplasm and cell sap) are known as HYPOTONIC, those with higher solute concentration HYPERTONIC.

When cells are placed in a hypotonic solution, water flows into the cell by the process of ENDOSMOSIS. In animal cells endosmosis can cause the cell to rupture, as the membrane cannot withstand the pressure exerted by the cell contents when swollen This is what happens when erythrocytes are placed in water They burst, leaving behind 'ghosts' of their membranes. In the plant cell such disruption is prevented by the presence of a rigid cell wall

You may have noticed water oozing out copiously from the surface of sliced cucumber sprinkled with salt. This results from EXOSMOSIS from its cells under the hypertonic effect of the salt In plant cells placed in a hypertonic solution the cytoplasm along with the plasma membrane withdraws from the cell wall, because of the outflow of water from the vacuole The vacuole shrinks but is still enclosed by the cytoplasm. This process is called PLASMOLYSIS (Fig 8.5A) In erythrocytes exosmosis causes a shrunken appearance or CRENATION (Fig. 8.5B)

(b) *Active Transport.* We often find that materials are transported into the cells against a concentration gradient. This often leads to accumulation of substances at a higher concentration within the cell than outside. Energy is required for such a process This is called ACTIVE TRANSPORT, as opposed to a passive diffusion where no energy is required. Active transport takes

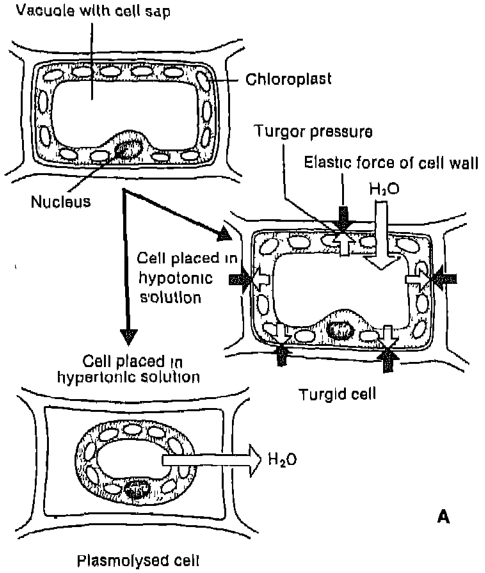
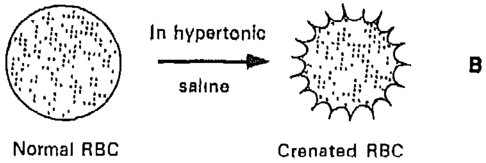


Fig. 8.5 Effect of hypertonic solution on a (A) plant cell and (B) animal cell



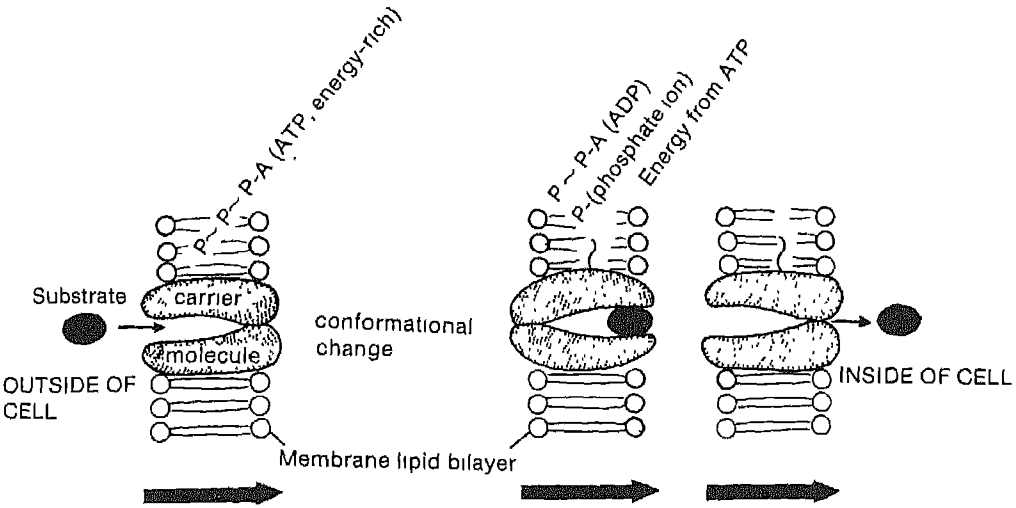


Fig 8.6 Diagrammatic representation of role of carrier in active membrane transport

place even against electrochemical gradients. The process is far more rapid than diffusion and is invariably in one direction. Unlike diffusion, active transport is affected by cold, cyanide and absence of oxygen

You may recall from Chapter 6 that some membrane proteins act as carrier molecules. A specific protein acts as a carrier for each molecule or ion (substrate). On one surface of the membrane, the carrier presents its binding site. On binding with the substrate the carrier undergoes a conformational change (Fig. 8.6). This transports the carrier bound substrate to the other side of the membrane, where it is discharged in an unaltered state. The carrier is left behind in the membrane. This process needs energy, which is supplied by ATP In the process ATP is converted to ADP.

Many cells have SODIUM-POTASSIUM EXCHANGE PUMPS in the plasma membrane. This is not to be confused with a cycle or a water-lifting pump. But just as a pump performs work against pressure or gravity, this is a mechanism for transferring Na^+ and K^+ ions against their electrochemical gradient This process utilises energy from ATP The integral protein involved in this pump is a Na^+-K^+ dependent ATPase (Fig. 8 7) For each molecule of ATP used, three Na^+ ions are pumped out and two K^+ ions are pumped in. The cell thereby maintains a far higher Na concentration outside the cell than within

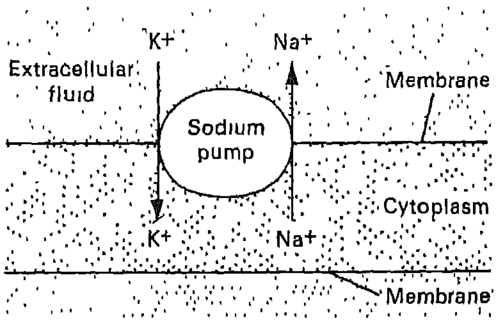


Fig. 8.7 Sodium – Potassium pump

Marine birds like seagulls and penguins drink sea water; but they elimiate the excess NaCl through secretions of their nasal salt glands. The sodium pump in the plasma membrane of the gland cells actively extrudes Na ions; this is accompanied by the passive movement of Cl^- Their nasal secretions consequently eliminate NaCl solutions, 1.5 to 3 times more concentrated than the blood.

Active transport enables the rapid, selective and exhaustive intake of many nutrients by the cells It helps to maintain ionic and water balance between cells and extracellular fluids. The process also aids in maintaining membrane potential by keeping the inner side of the membrane relatively electronegative to its outer side

Exocytosis and Endocytosis

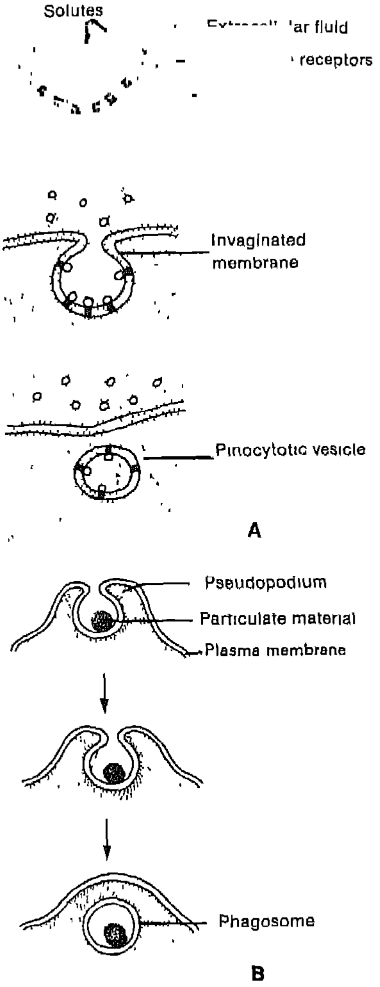
These are processes for active cellular extrusion and intake, respectively of such materials that cannot pass through the unbroken plasma membrane Such materials include macromolecules, large liquid droplets and particulate matter. Both processes involve movements and folding of the membrane, which are dependent on its fluidity and mobility. These require energy from ATP.

EXOCYTOSIS causes expulsion of materials from the cell. Secretory or exportable materials are stored in membrane-bound vesicles in the cytoplasm. Each vesicle moves to the plasma membrane and fuses with it. In this fused membrane, a channel opens between the lumen of the vesicle and the exterior of the cell, and the exportable material passes out.

ENDOCYTOSIS results in the active cellular intake of materials Endocytosis of droplets of extracellular fluid along with sub-microscopic particles is called PINOCYTOSIS (cell drinking) (Fig. 8 8A) PHAGOCYTOSIS (cell eating) is the ability of the cells to ingest or engulf solid particles (Fig. 8.8B).

Fig 8.8 A Pinocytosis of specific solutes with the help of membrane receptors

B. Phagocytosis of particulate material



Pinocytosis helps in the intake of solutes such as insulin and lipoproteins in concentrated form. Such extracellular solutes adhere to specific receptors of membrane and an invagination forms. (Fig. 8 8A) This is then drawn inwards and pinched off as a membrane-bound vesicle containing the solute. The pinocytic vesicle moves into the cytoplasm and its content are assimilated

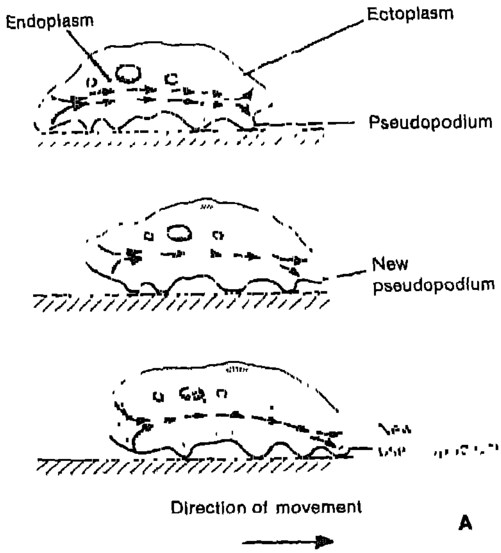
Phagocytosis is frequently used by protozoans such as *Amoeba* for engulfing food particles and by specialised mammalian cells called PHAGOCYTES (e.g , macrophages and WBC) for removing damaged cells, fibres, bacteria and dust particles The particulate material first gets bound to specific membrane receptors of the phagocyte. Antibodies bind bacterial cells to *receptors* This binding induces the outward projection of many thin protoplasmic extensions (PSEUDOPODIA). These meet and fuse to form a free-floating membrane bound vesicle enclosing the particle—the PHAGOSOME—the latter subsequently fuses with a LYSOSOME which releases enzymes to hydrolyse the contents

Role of Membranes in Cellular Movement

The plasma membrane participates in cellular locomotion in two ways:

(a) *Amoeba* and cells like macrophages and white blood cells (WBC) move by producing pseudopodia. New pseudopodia are continuously formed at the advancing end of the cell This depends partly on the cytoplasmic streaming towards that end, and the extension of plasma membrane of the advancing pseudopodia (Fig. 8.9A) Pre-existing pseudopodia are simultaneously retracted from the receding end.

(b) Some mammalian cells such as fibroblasts can move over a solid surface by the wave like undulations of the plasma membrane (Fig. 8.9B). This requires no cytoplasmic streaming Surface protrusions are formed on the cell due to ruffling or undulations of the membrane, which attach the cell temporarily to a solid surface. The portrusions move as waves to propel the cell.



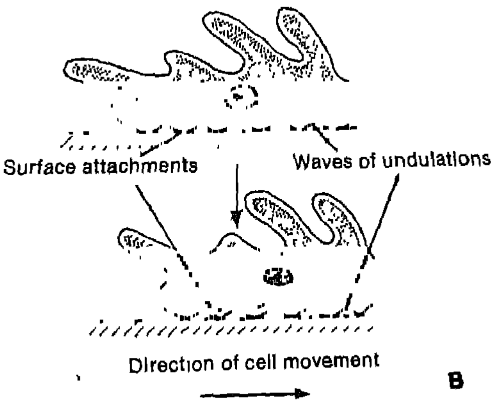


Fig. 8 9 A Movement in *Amoeba* by cytoplasmic streaming and pseudopodia formation

B. Undulatory waves moving a fibroblast on a surface

SUMMARY

Biological membranes include the plasma membrane and the membranes of the organelles. The plasma membrane keeps the contents of the cell separated from the extracellular fluid The organelle membranes segregate specific reactions and processes in the respective organelles.

According to the unit membrane concept, all biological membranes possess a common basic structure This consists of two outer layers of proteins and a middle layer of lipids.

According to the fluid mosaic model the membrane consists of a quasifluid phospholipid bilayer with embedded proteins Integral membrane proteins are firmly and deeply set inside the bilayer Peripheral membrane proteins are loosely held on the surface of the bilayer. The membrane shows considerable fluidity

Membranes participate in the exchange of materials. Passive membrane transport includes diffusion and osmosis, mostly through the membrane pores. Diffusion results from continuous random movements of diffusing particles Solutes and gases diffuse across the membrane down their electrochemical and pressure gradients

Osmosis is the net diffusion of a solvent (water in living systems), from a dilute to a concentrated solution across a semipermeable membrane When the cell is in an isotonic solution, no net osmotic flow occurs in any direction across its membrane and the cell retains its original form and volume When an animal cell is placed in a hypotonic solution endosmosis of water distends and ruptures it In a hypertonic solution, exosmosis of water causes crenation of animal cells and plasmolysis of plant cells.

Active transport requires energy expenditure. A membrane protein acts as a carrier to bind and transport the substrate in a specific direction across the membrane Active transport takes place even against electrochemical gradients Na^+-K^+- dependent ATPase actively transports Na^+ outwards and K^+ inwards.

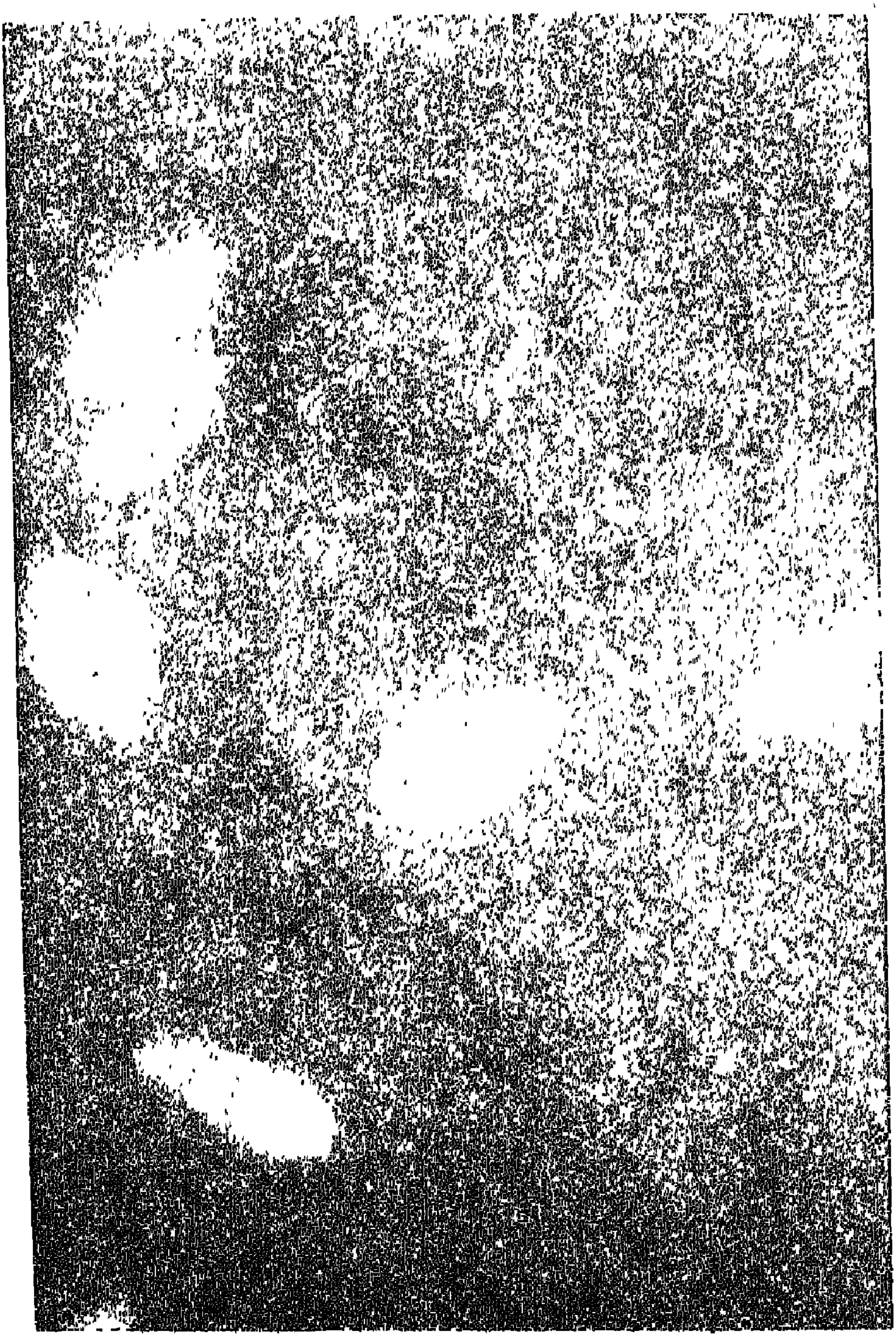
In exocytosis, a membrane-bound vesicle containing secretory materials fuses with the plasma membrane to extrude the materials out of the cell. Endocytosis is the active intake of macromolecular and particulate materials by the cell Pinocytosis is the endocytosis of dissolved solutes and liquids. The process of engulfing solid particles is termed phagocytosis.

Some membrane proteins act as receptors for informational molecules, others as carriers for transport, and still others help in cell recognition. Plasma membrane participates in cellular movements either by the formation of pseudopodia or undulations

QUESTIONS

1 Name the two main constituents of the plasma membrane and show how they are arranged by means of a diagram
2 Plasmolysis occurs when plant cells are placed in sucrose solution stronger than the cell sap.
   (a) what does the word "stronger" mean in this context?
   (b) sketch the various stages of plasmolysis occurring in a plant cell.

3. If a crystal of potassium permanganate ($KMnO_4$) violet in colour is placed on a clear layer of gelatin, the gelatin gradually becomes violet The colour is more intense in the vicinity of the crystal—
   (a) explain this observation.
   (b) discuss how this general process is important for living cells.
4 It is a common observation that after a plant is sprayed with a heavy dose of insecticides, yellowish areas appear on the leaves Investigations show that the cells have died Since the insecticide spray is not poisonous to plants, try to give reasons for the death of the cells
5. Why is it believed that food particles taken into *Amoeba* by phagocytosis remain "outside" the cell until digestion has occurred? Explain.
6. Two aqueous solutions, a 3% glucose solution and an 8% glucose solution are separated by a semipermeable membrane—
   (a) which solution has the greater osmotic pressure?
   (b) in which direction will osmosis occur?
   (c) which solution will increase in volume?
7 Recall that 0 9% NaCl and 5% glucose solution are isotonic to human erythrocytes Consider each of the following solutions, Indicate whether it is hypertonic, hypotonic or isotonic What sort of change will occur when erythrocytes are placed in it?
   (a) 5% NaCl (c) 0 89% NaCl (e) 10% glucose
   (b) 5% glucose (d) 0 2% glucose (f) 0 2% NaCl.
8 Which of the following are true (T) or false (F)?
   (a) The plasma membrane has a rigid structure
   (b) Membranes are useful for compartmentalisation in cells.
   (c) Solid particles are ingested by pinocytosis
   (d) All molecules can pass easily through a membrane if they are water soluble.
   (e) ATP is required for active transport
   (f) Sodium–potassium pumps helps to transport Na^+ ions and K^+ ions in both directions across a membrane.
9 How would you term the following processes?
   (a) Swelling of raisins (dried grapes) in water.
   (b) Exchange of gases during respiration
   (c) Intake of fluids through invagination of plasma membrane
   (d) Crenation of erythrocytes.
10. Why are membranes described as 'proteins in a sea of lipids'? Explain this statement with an example.
11. What is meant by active transport across a cell membrane?



CHAPTER 9

STRUCTURAL ORGANISATION OF THE CELL

IN the last few chapters you studied the various molecules which occur in cells and their roles At the next level of organisation molecules are assembled into subcellular components of the cell, such as the plasma membrane, cytoplasm, cytoskeleton, and organelles. In addition, certain procaryotic and eucaryotic cells possess cell walls. In this chapter you will learn about the electron microscopic structure and the functional importance of these components, which further highlight the basic unity of life

Cell Wall

The plasma membrane is covered by a cell wall in cells of bacteria, fungi, algae and plants The composition of the cell wall varies in the different kingdoms. In bacteria and some fungi the cell wall is composed of proteins and non-cellulosic carbohydrates. In certain fungi, most algae and higher green plants, cellulose forms the main component of the cell walls. The principal functions of the cell wall are protection, mechanical support, and maintenance of balance of intracellular osmotic pressure with that of its surroundings.

In the multicellular plants, cells do not move as they are firmly joined together like rooms in a building The layer that is common to two adjacent cells is called the MIDDLE LAMELLA and is composed of calcium pectate This is formed soon after cell division, and may be compared to the common brick wall between two rooms (Fig. 9.1). The PRIMARY WALL is laid on the middle lamella from within the cell. It consists of a loose network of cellulose MICROFIBRILS impregnated with a matrix of hemicellulose and pectin. The primary wall is thin and extensible and allows the young cell to grow. After a cell has reached maturity the cell forms a thick SECONDARY WALL, composed of at least three layers of microfibrils, laid down in succession in a gel-like matrix of hemicellulose (Fig 9.2) In some cells the secondary wall is impregnated with lignin to form wood, or with suberin to form cork The formation of the secondary wall is not even in all the cells. In plants this results in the differentiation of various

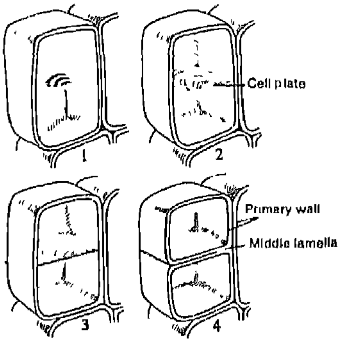


Fig. 9.1 Development of cell wall (marked 1, 2, 3 & 4) separating newly formed plant cells

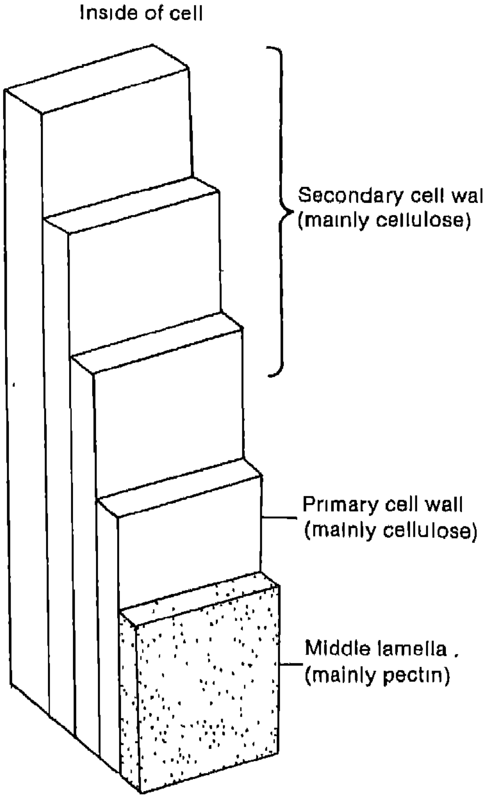


Fig. 9.2 The various layers that make up the cell wall of a mature plant cell

types of cells, such as parenchyma, sclerenchyma, collenchyma, fibres and trachids The position of the primary and secondary wall may be likened to the plaster and paint respectively in room.

The cell wall does not totally isolate a plant cell. It is interrupted by narrow pores carrying fine strands of cytoplasm which interlink the contents of the cells. These are called PLASMODESMA CONNECTIONS or PLASMODESMATA, and facilitate movement of substances between cells (Fig. 4.8)

Cell Coat

In many protistans and animals the cell membranes are not enclosed by cellulose walls Instead, a filamentous layer of oligosaccharides is laid down on the outer surface (Fig 9.3). It protects the underlying plasma membrane. It also helps in recognising other cells during tissue formation. It may be supported and strengthened by calcium salts, silicon or other materials

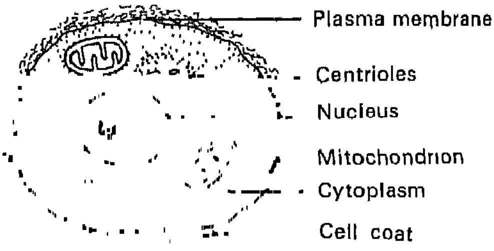


Fig. 9.3 Cell coat

Cytoplasm

The term 'cytoplasm' is used for the jelly-like, fluid, general mass of protoplasm, excluding the nucleus, covered by the plasma membrane and containing the organelles. Nucleotides, vitamins, t RNA, enzymes, many minerals, sugars and amino acids remain in solution in the cytoplasm. Proteins occur in the form of colloidal sols

Cytoplasmic Streaming (Cyclosis) This refers to the movement of cytoplasm within the eucaryotic cells. Streaming helps in the formation of pseudopodia in amoeba and in the movement of organelles and other cell inclusions. Cytoplasm may move in one direction around a central vacuole or in several directions around vacuoles. Cyclosis depends on the viscosity of the cytoplasm and temperature.

Activity: Mount a fresh young *Hydrilla* leaf in water and observe the cells in the vicinity of the mid-rib under the high power of a microscope. You will be able to see the chloroplasts moving in one direction. Alternatively, observe under the high power of the microscope the staminal hair cells of *Tradescantia*, by mounting a filament Cyclosis in these cells occurs in several directions

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What are main activities or processes that occur in the cytoplasm? The cytoplasm participates in the intracellular distribution of nutrients, metabolites and enzymes and in the exchange of materials between organelles Glycolysis or the breakdown of glucose, and biosynthesis of fatty acids, nucleotides and many proteins take place in the cytoplasm.

Nucleus

The nucleus is the principal organelle of the cell. It is a dense round or irregularly shaped body. Most cells are uninucleate; some are binucleate (in certain protozoans) and others multinucleate Some organisms may contain several nuclei in their large body which is not divided into cells and are called COENOCYTIC (certain fungi such as *Rhizopus* and the alga *Vaucheria*)

When an unstained living cell is observed under a light microscope, the nucleus may not appear to contain anything inside When a cell is fixed (killed in proper chemicals) and stained with suitable dyes, several structures become noticeable in the nucleus. Within the semi-fluid ground substance of the interphase nucleus, the NUCLEOPLASM or KARYOPLASM, one or more round bodies termed NUCLEOLI (singular NUCLEOLUS) are seen A network of dark-staining fibres—the CHROMATIN—is visible in the nucleoplasm Prior to the division of the nucleus, the chromatin strands condense to distinct threads called CHROMOSOMES. Chromosomes are largely made of proteins and DNA and bear the genes, which are units of hereditary information. Every chromosome shows a constricted part called the CENTROMERE.

In an electron micrograph you will note that the nucleus is surrounded by a double membrane layer called the NUCLEAR ENVELOPE (Fig. 9.4). It consists of two NUCLEAR MEMBRANES separated by a fluid filled space, the PERINUCLEAR SPACE continuous with the lumen of the ROUGH ENDOPLASMIC RETICULUM (RER) Many NUCLEAR PORES are observed in the nuclear envelope The two nuclear membranes

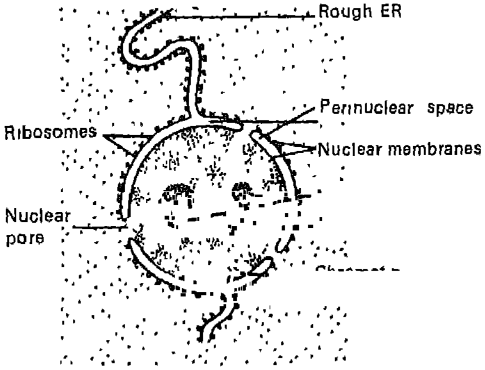

Fig. 9.4 Nucleus

are continuous at the margin of each pore. The nuclear envelope is seen in a non-dividing cell (INTERPHASE NUCLEUS). It disappears during cell division and reappears round the two daughter nuclei.

The nucleus has two major functions. It contains the genetic information for reproduction, development, metabolism and behaviour of the organism. It can duplicate this information and pass it on to the daughter cells. Secondly, the nucleus contains directions for controlling cellular activities. It dictates what enzymes are to be formed and when, through the formation of RNA. In addition the nucleolus takes part in the production of RIBOSOMES.

Mitochondria

These membrane-bound organelles called, 'power houses' of the cell, are essential for aerobic respiration of eucaryotic cells. Mitochondria are usually sausage-shaped, several μm in length and up to several hundred nm in diameter. Spherical, oval, pear-shaped, cylindrical and filamentous mitochondria are not uncommon. The shape and size of mitochondria vary with the kind of cellular activity. The number of mitochondria increases with cellular activity. For example, cells of germinating seeds show a much larger number of mitochondria than those of dormant seeds.

A liver cell carries about 500-1000 mitochondria; a striated muscle fibre contains many thousands; some oocytes possess about 30,000 mitochondria. Plant cells have fewer mitochondria than animal cells.

Mitochondria are randomly distributed throughout the cytoplasm in some cells. The density of mitochondria is higher in cells involved in energy-dependent activities. For example, mitochondria are aggregated at the bases of CILIA to supply energy for movement and at the light band of muscle fibres to produce energy for contraction.

Mitochondria are SEMI-AUTONOMOUS ORGANELLES. They contain DNA, mRNA and RIBOSOMES and synthesise some of their own proteins. However, many of their proteins come from the cytoplasm. During cell division each daughter cell inherits mitochondria from the mother cell. These mitochondria subsequently replicate to restore the normal number of mitochondria in the cell.

The detailed structure of a mitochondrion can only be seen with the help of an electron microscope (Fig. 9.5). A

Fig. 9.5 Mitochondria as viewed under the electron microscope. Note the prominent cristae.

mitochondrion is enclosed by a double-membrane envelope (Fig. 9.6). The two membranes of the envelope are separated by a narrow fluid-filled space called the OUTER COMPARTMENT. The OUTER MEMBRANE is smooth It is more permeable to small molecules, contains some enzymes, but is poorer in proteins than the INNER MEMBRANE. The inner membrane surrounds a central cavity or matrix (INNER COMPARTMENT) filled with a fluid. The inner membrane is more selective in its permeability, and is rich in enzymes and carriers. Many folds of the inner membrane project into the matrix as incomplete partitions. These folds, called CRISTAE (singular CRISTA) increase the surface area of the inner membrane. The space between the membranes of each crista is continuous with the space in the outer compartment

The fluid-filled matrix is rich in enzymes, particularly of the Krebs tricarboxylic acid (TCA) cycle. A circular double-stranded DNA molecule and many small ribosome granules also occur in the matrix.

The inner membrane and cristae bear numerous particles which have a spherical head subtended by a stalk (Fig. 9.6). The spherical head-piece or F_1 SUBUNIT of each particle projects into the matrix from the membrane It is connected by a cylindrical stalk to a base piece or F_0 SUBUNIT. The F_1 subunit is an integral protein embedded in the membrane lipid. The F_0–F_1 combination functions as ATP

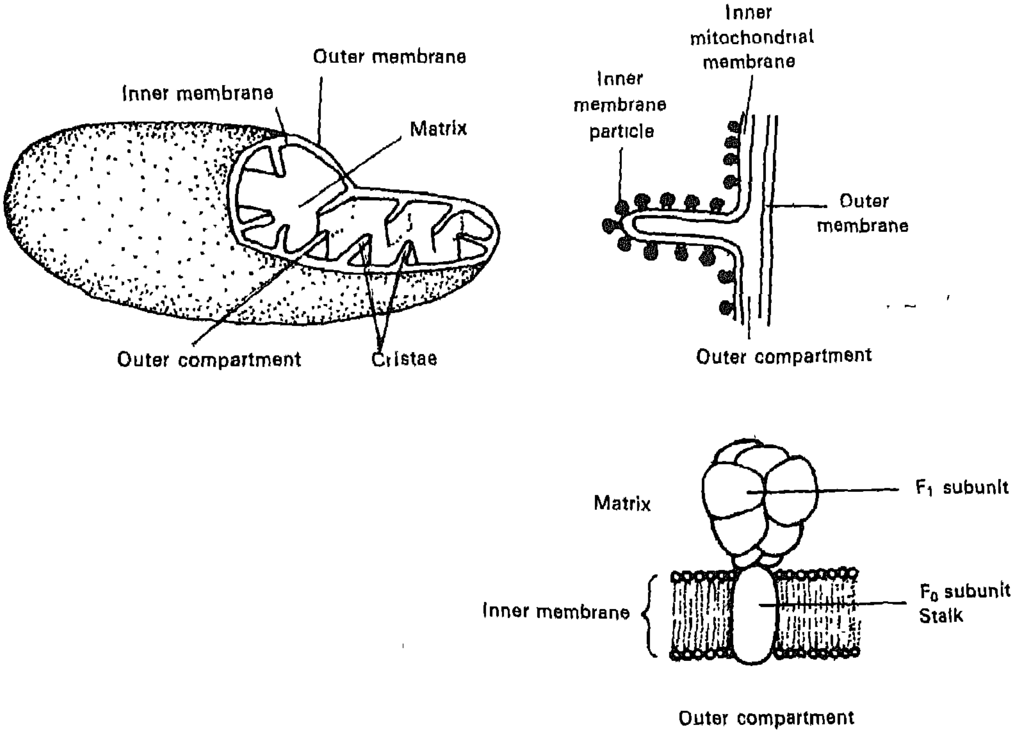

Fig 9.6 Inner structural details of a mitochondrion

SYNTHASE, an enzyme that catalyses ATP synthesis.

Mitochondria function mainly as compartments for aerobic respiration and ATP synthesis. You will learn more about their function in the next chapter

Plastids

Plastids are organelles enclosed by a double-membrane, found only in plant cells. They are of different types varying in shape, size, colour and function.

CHLOROPLASTS are green plastids containing the pigment chlorophyll. These are the photosynthetic organelles of green plants Chloroplasts may be lens-shaped, oval, spherical, cup-shaped, discoid, polygonal or ribbon-like A leaf parenchyma cell may have 20–40 chloroplasts

Each chloroplast is covered by a double-membrane (called the ENVELOPE MEMBRANE((Fig. 9 7), containing a space filled with a colourless proteinaceous matrix called STROMA. Both membranes are smooth The inner membrane is less permeable than the outer, but is richer in proteins, including some carrier proteins

The stroma contains a small circular double-helical DNA, ribosomes and several enzymes. Many flat membranous structures called THYLAKOIDS occur in the stroma (Fig 9 8). About 20-50 thylakoids are placed one above the other like a stack of coins to form a *granum*. About 40–100 grana usually occur in a chloroplast Many membranous tubules, called STROMA LAMELLAS interconnect thylakoids of different grana

The main function of the chloroplast is to trap solar energy and convert it into chemical bond energy in photosynthesis You will learn more about this process in Unit Five.

LEUCOPLASTS are colourless plastids Oval spherical, rod-like or filamentous leucoplasts occur in large numbers in cells of fruits seeds tubers and rhizomes They [illegible] potato

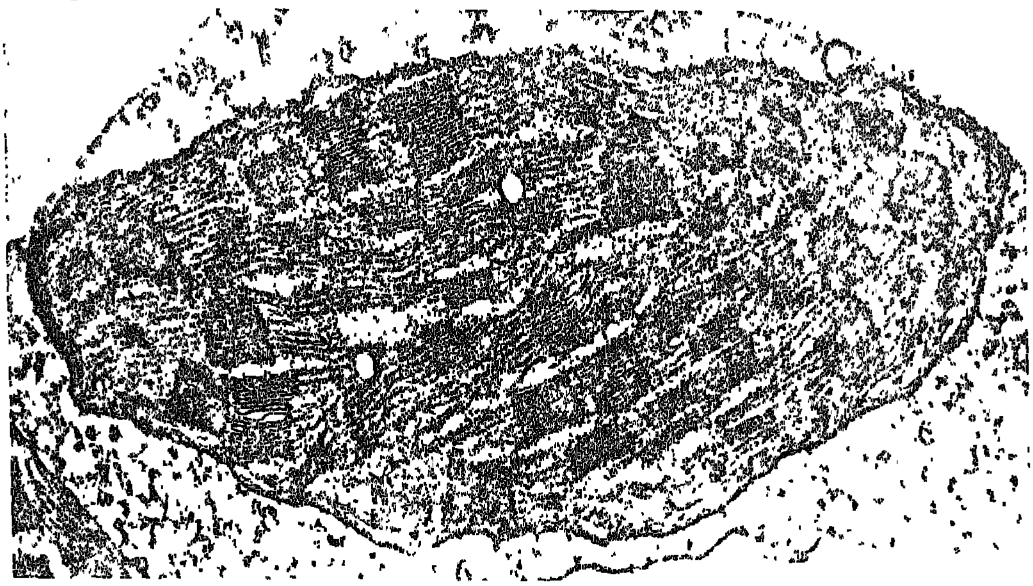

Fig 9.7 Electron micrograph of a chloroplast

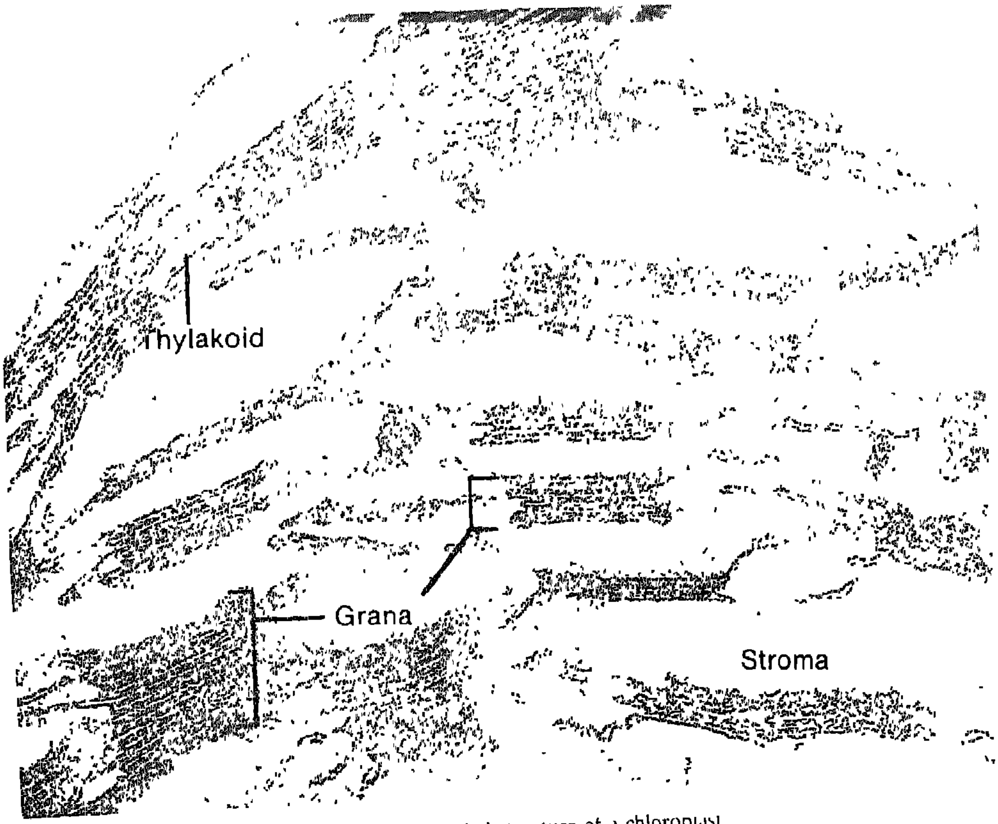

Fig. 9.8 Detailed structure of a chloroplast

store starch. CHROMOPLASTS are coloured plastids, containing fat soluble yellow orange and red pigments chiefly carotenoids These are found in flowers and fruits.

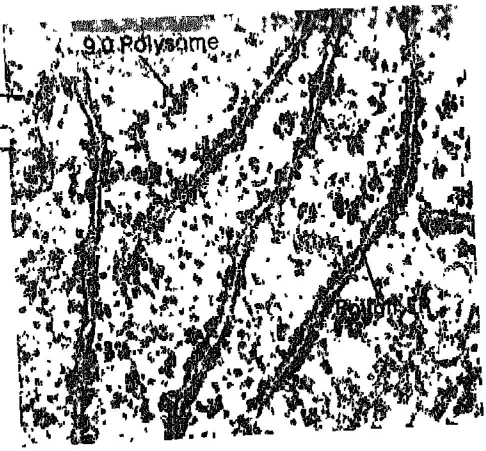

Fig. 9.9 Electron micrograph of rough endoplasmic reticulum and polyribosomes

Endoplasmic Reticulum

Endoplasmic reticulum (ER) consists of an intercommunicating system of channels made of membranous sacs (*cisternae*), vesicles and narrow tubules occurring in close packed stacks around the nucleus Their lumen is filled with a fluid, The name of the organelle is derived from the network (reticulum) of its cisternae and tubules in the cytoplasm (Fig 9.9). ER synthesises

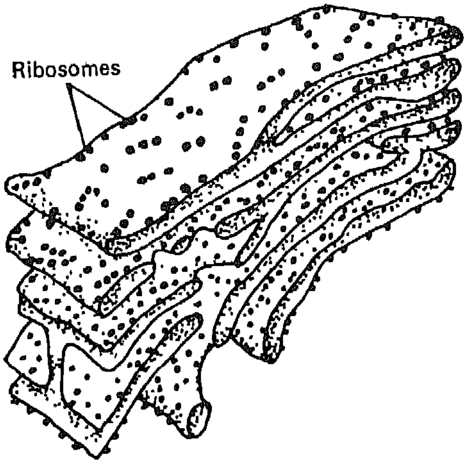

Fig 9.10 A 3-dimensional view of rough endoplasmic reticulum

secretory materials and membrane constituents.

ER contains many enzymes and other proteins. Two kinds of ER are observed in cells: (i) *smooth ER (SER)* and (ii) *rough ER (RER)*. RER has membranes with ribosomes attached to the cytoplasmic surface (Fig 9.10). This makes the surface rough or granular, like coarse sand paper. The channels are formed by two sheets of this 'sand paper' lying side by side, with their rough surface facing outwards. Unlike RER, SER has smooth-surfaced membranes, free from ribosomes and consists mainly of tubules and vesicles. RER on the other hand is made of cisternae and a few tubules. The RER membrane is continuous with the SER membrane and the outer membrane of the nuclear envelope. The SER membrane is in turn continuous at places with the membrane of the Golgi cisternae and plasma membrane

RER and SER have some specialised functions and some common functions. Numerous flat RER cisternae found in protein secreting cells such as fibroblasts, cells of pancreas and liver synthesise secretory proteins and membrane proteins. SER is found in abundance in lipid and sterol secreting cells such as liver, adrenal cortical and fat cells. The function of SER is to synthesise lipids and sterols Together they form passages for transport of secretory proteins, lipids and sterols.

Golgi Complex

Golgi complex or Golgi body (sometimes referred to as dictyosomes in plants) is a major organelle. It consists of one or more stacks of flat, expanded intercommunicating cisternae (Fig. 9.11) A cisterna is a fluid-filled lumen enclosed by a single smooth membrane A large number of such stacks occur in the pancreatic and goblet cells. The stacks are usually located between the ER and the plasma membrane (Figs. 4 6 & 4.8). Each stack has about 4-8 closely packed almost parallel cisternae, separated from each other by thin layers of cytoplasm. Cisternae are curved like shallow bowls Golgi cisternae have continuities of lumen with each other and with SER tubules Secretory materials reach the Golgi complex through these portions of

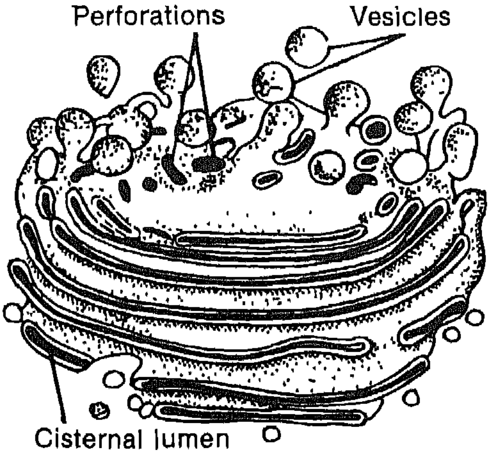

Fig. 9.11 Golgi body

through TRANSITIONAL VESICLES which are pinched off from the SER and fuse with the Golgi cisternae.

The lumens of ER cisternae and tubules and Golgi cisternae communicate with each other forming passages for transport of secretory protiens, lipids and sterols Membranes of ER and Golgi cisternae are also continuous with each other, so membrane proteins and lipids may flow onwards along their membranes

Secretion is the main function of the Golgi complex. The secretory proteins and lipids are concentrated and packed into SECRETORY VESICLES or GRANULES These are pinched off from the dialated tips of cisternae and appear as dense SECRETORY or ZYMOGEN GRANULES in the cytoplasm Ultimately the vesicles release their contents by exocytosis

The Golgi complex participates in the recycling of plasma membrane. Vacuoles or vesicles, pinched off from Golgi cisternae, fuse with the plasma membrane thus adding new stretches of membrane. Stretches of plasma membrane pinched off by pinocytosis form vesicles which fuse with the Golgi cisternae Golgi vesicles also form the cell plates after cell division in plants.

Lysosomes

These membranous vesicles occur both in plants and animals They are spherical-to-irregular in shape and vary in size. A lysosome has a single membrane. The lysomes are budded off from Golgi cisternae or ER tubules. The lumen of a lysome is filled with a finely granular fluid rich in digestive enzymes, the ACID HYDROLASES A lysosome fuses with an endocytotic vacuole (*phagosome*) or a damaged organelle or a secretory granule. Its enzymes hydrolyse the materials included in the fused vesicle. The products are released into the cytoplasm for reprocessing into new molecules. After some time the lysosome left with unhydrolysed residues in its lumen is called the RESIDUAL BODY. It may either keep the residues isolated inside it or disappear by discharging the residues outside the cell

The lysosomes release hydrolases in [illegible]s to digest them (AU- [illegible]sts aptly call lysoso- [illegible]osomal enzymes may also be released outside the cell to breakdown extracellular materials. When tadpoles undergo metamorphosis into adult frogs or toads, their tails are lost This is due to the action of lysosomes which hydrolyse the substances in the tissues of the tail and make them available for the development of the frog.

Microbodies

These are spherical or oval vesicles, enclosed by a membrane and are filled with a fluid matrix, PEROXISOMES are microbodies (0.5-1 μm) in liver cells and leaf parenchyma cells. The matrix of peroxisomes contains peroxide-destroying enzymes (catalases) and peroxide-producing enzymes. They prevent peroxides from acting on the cellular contents. GLYOXISOMES are microbodies in the cells of germinating fatty seeds such as groundnut and castor. These are associated with the breakdown of fats

Ribosomes

These granular organelles are not enclosed by any membrane. Each ribosome consists of two unequal subunits composed of RNA and proteins. Eucaryotic cells carry ribosomes of different sizes. Ribosomes present in the cytoplasm and on RER membrane are about 20-25 nm in diameter The ribosomes of the chloroplast stroma and mitochondrial matrix are much smaller. About 6-8 ribosomes become attached to an mRNA molecule to form a linear beaded string called POLYSOME or POLYRIBOSOME (Fig 9.9). Ribosomes are sites of protein synthesis You will learn about the mechanism of protein synthesis later.

Cytoskeletal Structures

The cytoplasm of eucaryotic cells contains an extensive network of minute tubules and filaments, appropriately called MICROTUBULES and MICROFILAMENTS These form the structural framework within the cell, and maintain the shape of the cell and its extensions. The distribution and orientation of organelles are also regulated by them

Microfilaments

These are long, thin, cylindircal rods (6-10 nm in diameter) composed of mainly the protein *actin* Association of actin microfilaments with filaments of the protein myosin is essential for the contraction of the microfilaments. Microfilaments form an extensive network in the cytoplasm, some are associated with the plasma membrane on its cytoplasmic surface, and others extend into the cytoplasmic core of MICROVILLI Microfilaments are responsible for the movement of the plasma membrane during cell mobility and endocytosis, contraction of muscle fibres, and movement of microvilli

MICROVILLI are thread-like protoplasmic projections on the free surface of absorptive cells such as intestinal cells. Each microvillus is covered by an extension of the plasma membrane Many microfilaments run longitudinally in its core and are anchored to the plasma membrane at the tip. Microvilli increase the free surface of the cell to enhance absorption. Contractions of microfilaments move the microvilli causing the external medium to flow and thus help in absorbing materials from a larger area.

Microtubules

These are elongated, unbranched cylindrical tubes about 25 nm in diameter. Each tubule encloses a light central core of about 15 nm in diameter (Fig. 9.12) The wall of a microtubule is made of 13 longitudinal filaments, each a polymer chain of TUBULIN Microtubules occur singly or in bundles in the cytoplasm. They radiate from the CENTRIOLES to the peripheral parts Microtubules form the skeleton of cilia and flagella and the spindle during cell division. Microtubules help in the maintenance of cell form, cell mobility and movement of chromosomes. A unique feature of the microtubules is the ease with which they can be broken down and reassembled in another part of the cell.

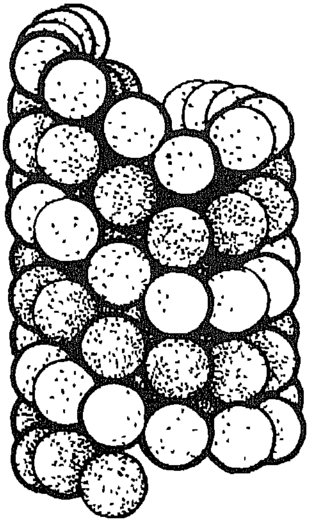

Fig. 9.12 Structure of a microtubule

Cilia and Flagella

These are fine, hair-like, movable projections from the surface of some cells These are structurally almost identical but differ in length, number per cell and in motion Cilia are short, numerous and move in a characteristic rowing fashion The number of flagella is restricted to one or a few. These are longer than cilia and have a wave-like motion. A cilium or a flagellum is enclosed by an extension of the plasma membrane (Fig. 9.13). A cross section of a flagellum shows nine pairs of microtubules in the periphery and two single microtubules in the cente (9+2 arrangement). The sliding of the microtubules causes the movement of cilia and flagella

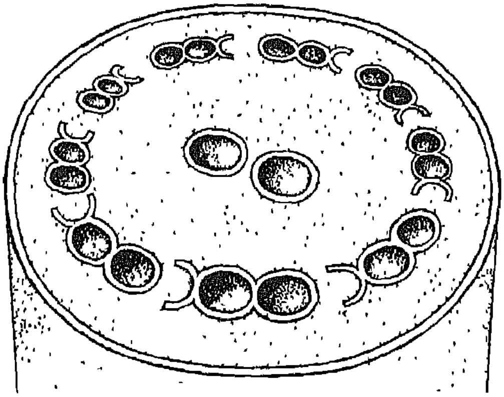

Fig. 9.13 Diagram showing arrangement of microtubules (9+2) in cilia or flagella Microtubules are enclosed by an extension of the plasma membrane

Below each cilium or flagellum in the cytoplasm of a cell is a BASAL BODY. In cross section the basal body shows a ring of nine triplets of microtubules but lacks the two central microtubules (9+0 arrangement). The basal body serves as the starting point for the production of cilia and flagella

The beats of a cilium consist of two strokes (Fig. 9 14). During the POWER STROKE the cilium moves against the surrounding medium with force This causes the movement of the medium in the direction of the stroke and that of the cell in the opposite direction. But during the RECOVERY STROKE the cilium returns to the original position with a flexible movement. This mechanism can be compared to the rowing of a boat. In the power stroke the boat moves forward as the oars are stroked backwards. The oars are brought back by lifting them above water. In multicellular organisms, ciliary movements cause fluids or particles to move over the cilia bearing surface in the direction of the power stroke.

A flagellum shows several symmetrical undulatory waves passing from base to tip of flagellum (Fig. 9 14). These drive the organism in the direction opposite to that of the flagellum. Flagellar movements of spermatozoa propel them head forward within the fluid medium of the female reproductive tract

> Cilia of tracheal and bronchial cells move the inhaled dust particles towards the pharynx. This minimises the entry of the inhaled particulate materials into the lungs. Cigarette smoking may temporarily reduce or suspend ciliary movements of these cells. Air-borne particles enter the smoker's lungs more easily than a non-smoker's lung

Centrioles

These non-membranous organelles are found in animal cells and in flagellated plant cells, such as motile algae, and motile sex cells of some primitive land plants. These occur in pairs at right angles to one another near one pole of the nucleus (Fig. 4 6) Each centriole is made of nine triplets of

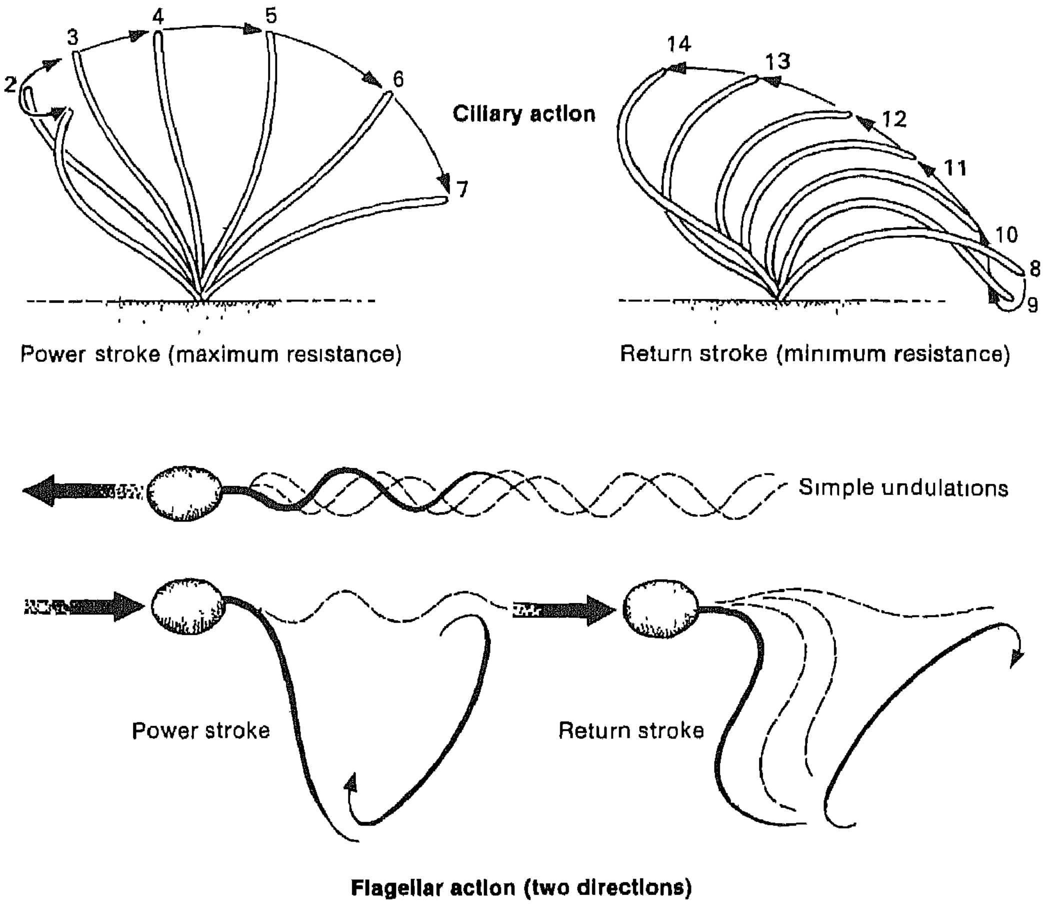
2
3
4
5
6
7
Ciliary action
14
13
12
11
10
8
9
Power stroke (maximum resistance)
Return stroke (minimum resistance)
Simple undulations
Power stroke
Return stroke
Flagellar action (two directions)

Fig. 9.14 Ciliary and flagellar movement

microtubules having the same arrangement as the basal body (Fig. 9.15).

The centrioles separate and migrate to opposite poles of an animal cell during cell division, from where they function as centres for the organisation of the spindle In the interphase between two cell divisions, pre-existing centrioles replicate to form two pairs, one for each daughter cell. Centrioles are also involved in the organisation and development of cilia and flagella The centrioles move to the periphery of the cell and become basal bodies. In the development of cilia, the cen-

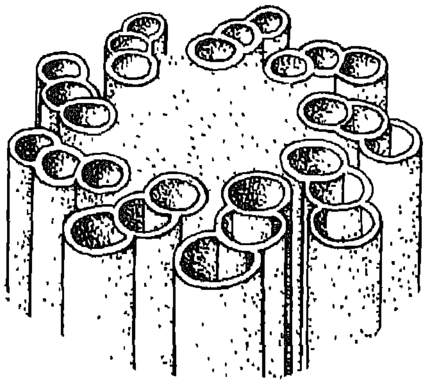

Fig. 9.15 Arrangement of microtubules (9+0) in a centriole

trioles divide many times and orient themselves along the surface of the cell to form numerous basal bodies

Vacuoles

You already know that vacuoles are sap-filled vesicles in the cytoplasm, covered by a membrane called the tonoplast The vacuolar sap contains minerals, sugars, amino acids, proteins, esters, water-soluble pigments, and waste products in solution or as crystalline deposits. Animal cells and enlarging plant cells have a few small, scattered vacuoles In mature plant cells vacuoles fuse to form one large central vacuole.

Some protozoan cells contain CONTRACTILE VACUOLES, which enlarge by accumulating fluids and collapse by expelling them from the cell.

The tonoplast is a semipermeable membrane and enables the vacuole to segregate, concentrate and store nutrients and waste products. Since the large vacuole spreads the cytoplasm into a thin layer, it facilitates the rapid exchange of solutes and gases between the cytoplasm and adjoining fluids

Cell Inclusions

These include both organic storage materials and inorganic crystals

(a) STARCH GRAINS occur in plant cells only, particularly in storage organs such as rhizomes and tubers. They are spherical, oval, elliptical or polyhedral bodies Each grain may have concentric or eccentric rings of starch around a *hilum* made of protein.

Activity Take a small amount of maize or wheat starch on a thin slice of potato in a drop of water on a slide. Place a cover slip and examine under the high power of the microscope You will observe various shapes and sizes of starch grains Try to locate the hilum. On being stained with dilute iodine solution, the starch grains will appear dark blue

(b) GLYCOGEN GRANULES are small, spherical or large rosette-shaped particles occurring near the SER in liver and muscle cells.

(c) FAT DROPLETS are found in adipocytes (fat-storing cells) of animals. One or several large fat droplets fill up the cell. The cytoplasm and organelles are pushed to the periphery Fat globules are also seen in the cells of the endosperm of castor and coconut and of the cotyledons of groundnut and mustard seeds.

(d) ALEURONE GRAINS contain stored proteins in plant cells They are conspicuous in the outermost cells of the endosperm in the cereal grains such as maize, wheat and barley.

(e) CRYSTALS of various chemical compounds occur in plant cells. Of these, the most common ones are of calcium (calcium oxalate, calcium carbonate and calcium sulphate) and silica Crystals of organic substances are not infrequent The crystals are of various shapes.

Activity Collect some duckweed (*Lemna*) plants fronds from a pond Store these for a few days in 75 per cent alcohol till they become colourless. Mount a plant in dilute glycerine and observe under the high power of the microscope. Cells containing bundles of needle-like crystals (RAPHIDES) will be seen.

SUMMARY

Even the tiniest cell has a complex internal structure. The electron microscope has enabled biologists to identify the various cellular components. We now know a good deal about the composition and functions of the different structures. All eucaryotic cells are covered by a plasma membrane. A plant cell is further encased in a rigid, porous, cellulosic cell wall outside the membrane. The cell wall gives mechanical support to the cell and protects it against osmotic overdistension. The surface of some animal cells is covered by a filamentous layer—the cell coat, which helps in the recognition and adhesion of cells.

Cytoplasm is the jelly-like fluid mass of protoplasm excepting the nucleus. The cytoplasm contains organelles, dissolved organic and inorganic substances, proteins and cell inclusions. Cyclosis helps in the formation of pseudopodia and movement of organelles. Cytoplasmic enzymes carry out glycolysis and biosynthesis of fatty acids and many proteins.

Nucleus is the principal organelle of the cell. It is covered by a double-membrane called the nuclear envelope, traversed by many pores. It encloses a fluid called nucleoplasm in which one or more dense nucleoli and chromatin occur. Chromatin fibres are made of DNA and proteins. Prior to division the chromatin condenses and becomes separated into distinct threads called chromosomes. The chromosomes bear the genes. The nucleus controls all cellular activities.

Mitochondria are called 'power houses' of the cell. They are covered by a double-membrane and enclose a fluid matrix inside. The inner membrane forms many folds called cristae which penetrate into the matrix. The inner membrane and its cristae bear many protein particles and carry electron transport enzymes. Mitochondria are sites of aerobic respiration and ATP synthesis.

Chloroplasts are plastids that contain chlorophyll and are covered by a double-membrane. In the stroma inside them, membranous structures called thylakoids form many stacks called grana. Chlorophyll is found in thylakoid membranes which carry out photosynthesis. Other types of plastids found in plants are leucoplasts, amyloplasts and chromoplasts.

Endoplasmic reticulum (ER) consists of interconnected membranous cisternae and tubules in the cytoplasm. Rough ER (RER) bears ribosomes on its membrane surface and synthesises secretory and membrane proteins. Smooth ER (SER) is free from ribosomes and synthesises lipids and sterols.

Golgi complex consists of stacks of flat, membranous cisternae. It helps to concentrate secretory materials and packs them into secretory vesicles.

Lysosomes termed 'suicide bags' of the cell are memrbanous vesicles which store acid hydrolases in their fluid contents. They fuse with the endocytotic vesicles or damaged organelles and hydrolyse them.

Microbodies include peroxisomes and glyoxisomes. They are membranous vesicles containing peroxide-producing and peroxides-destroying enzymes. They protect the cell from damage by peroxides.

Ribosomes are granules made of rRNA and proteins. They participate in protein synthesis in the cytoplasm, mitochondria and chloroplasts. Ribosomes occur singly or as polysomes in the cytoplasm and on the RER membrane.

Microfilaments and microtubules form the structural framework of the cell and its processes They function in the movements of microvilli, cilia and flagella Microvilli are thin protoplasmic projections on the free surface of a cell. Cilia and flagella are mobile processes on the free surface of a cell They cause the movement of a free cell in a fluid medium Cilia also move materials over the cell surface

Centrioles are paired cylindrical structures found near one pole of the nucleus Their wall is formed of 9 sets of microtubule triplets. They are found mainly in animal cells They are associated with spindle formation during cell division and in the formation of basal bodies which in turn give rise to cilia and flagella.

Vacuoles are fluid-filled vesicles in the cytoplasm Mature plant cells have a single large vocuole, which spreads the cytoplasm in a thin peripheral layer

Nonliving inclusions like starch grains, glycogen granules and fat droplets are stored inside the cytoplasm Crystals of various organic and inorganic substances are also found in certain cells

QUESTIONS

1. Distinguish between
   (a) cytoplasm and nucleoplasm
   (b) chromatin and chromosome
   (c) microtubules and microfilaments
   (d) leucoplasts and chromoplasts.
2. State the main functions of the following.
   (a) ribosome (b) lysosome (c) chromosome (d) peroxisome
3. Where would the follwing structures be found in a cell?
   (a) microtubules (b) thylakoids (c) F_0–F_1 complex (d) ribosomes (e) nucleolus
4. List the functions of rough and smooth endoplasmic reticulum and Golgi bodies
5. What are the two principal roles of the nucleus? What biomolecule is responsible for these roles?
6. What structural and functional characteristics do cilia, flagella and centrioles have in common?
7. Which of the following are found exclusively in plants cells, exclusively in animal cells, and in both?
   i nucleus ii centrosomes iii. Golgi bodies iv. leucoplasts
   v cell coat
8. Match the different items in column I with appropriate items in column II

Column I	*Column II*
A Polyribosomes	a. RER
B. Acid hydrolases	b protein synthesis
C SER	c lysosomes
D. Thylakoid	d. grana
E. Cristae	e mitochondria
	f steroid synthesis

9 Which of the following belong to a distinct category?
   (a) i. Nucleus ii. vacuole iii cell wall iv chloroplast
   (b) i Nucleus ii Nucleoli iii centriole iv chromosome
   (c) i Centriole ii basal body iii flagella iv. microvilli

10 Tick (√) mark the answer in each case.
   (a) Plant cells differ from animal cells in having
      (i) mitochondria
      (ii) cell wall
      (iii) ribosomes
      (iv) Golgi bodies
   (b) The cell wall of certain fungi is made of
      (i) lignin
      (ii) suberin
      (iii) chitin
      (iv) pectin
   (c) Aerobic respiration is performed by
      (i) glyoxisomes
      (ii) mitochondria
      (iii) lysosomes
      (iv) chloroplast
   (d) The chloroplast thylakoids are in the form of
      (i) interconnected sacs
      (ii) interconnected tubules
      (iii) independent discs
      (iv) stacked discs
   (e) The interphase nucleus is enclosed in
      (i) a non-porous double membrane
      (ii) a non-porous single membrane
      (iii) a porous double membrane
      (iv) many membranes

11. Observe the relationship between the first two words and then fill in the suitable word at the fourth place
   (a) Centriole : 9+0 : Cilia :__________
   (b) Mitochondria : cristae : chloroplast:__________
   (c) Chloroplast : photosynthesis : amyloplast __________
   (d) Nucleus : light microscope :: ER :__________

12 Supply the specific scientific terms for the folowing
   (a) Cluster of ribosomes found in cytoplasm
   (b) Extensive infoldings of the inner membrane of mitochondria
   (c) Stacks of closely packed thylakoid
   (d) Stalked particles on the inner membrane of the mitochondria.

CHAPTER 10

CELLULAR RESPIRATION

ALL living cells require energy for synthesising cellular components and for carrying out various functions such as uptake of materials, growth, development and movement Energy is also required by some organisms to keep the body warm and for locomotion. The energy needed by cells is obtained from the oxidation of complex organic compounds by CELLULAR RESPIRATION. Even green plants that trap solar energy by photosynthesis and store it as organic compounds, depend on respiration for their continuous energy supply.

Oxidation of the organic compounds taken in as nutrients, has to be conducted in steps for controlled release of energy. About 50 per cent of the total energy released during respiration may be utilised for the synthesis of biomolecules and other life activities In contrast, the energy from combustion in nonliving systems is mostly released as heat and sometimes partly as light The difference arises from the stepwise release of energy in living systems and the coupling of each energy-yielding step with the synthesis of ATP Biological oxidation may yield as much as 100 kcal per mol of oxygen reduced. This energy is then used to synthesise 6 high energy bonds of ATP. You will learn later in this chapter how the various steps in the process of respiration are necessary for utilising the released energy more efficiently

All cells have the necessary structural organisation and enzymes to carry out the oxidative process in small steps. In this process organic compounds, mainly carbohydrates, are oxidised by the removal of hydrogen and produce carbon dioxide. In most organisms oxidation needs the participation of molecular oxygen obtained from outside. Oxygen is ultimately reduced to form water. Thus oxidation of carbohydrates, besides releasing energy, leads to the formation of carbon dioxide and water.

The carbon dioxide produced in respiration must be removed from the cell. RESPIRATION thus involves exchange of gases between the cell and its surroundings, as also between the organism and its environment Lavoisier had demonstrated that animals take in oxygen from the air and give out carbon dioxide and water. A multicellular organism, depending on its habitat, exchanges the respiratory gases either with a liquid or a gaseous environment But in a cell gaseous exchange occurs in a liquid medium

The substrate most commonly oxidised in cellular respiration is glucose Fatty acids and amino acids are also utilised to some extent. But they are initially oxidised and broken into intermediates identical with those in sugar oxidation. The intermediate metabolites from all three sources are finally oxidised through a common oxidative pathway called the KREBS TRICARBOXYLIC ACID CYCLE (TCA CYCLE).

Cellular respiration may be classified into two types, according to its dependence on oxygen. AEROBIC RESPIRATION requires the presence of molecular oxygen and occurs in mitochondria ANAEROBIC RESPIRATION does not require the presence of oxygen and is catalysed by enzymes present in the cytoplasm. Both types of respiration have a common series of initial steps termed GLYCOLYSIS. Glycolysis (meaning literally sugar-splitting) occurs in the cytoplasm and results in the breakdown of glucose into pyruvic acid, a compound with three carbon atoms

Glycolysis

During glycolysis (Fig. 10.1) glucose ($C_6H_{12}O_6$) is changed to glucose-6-phosphate, and glucose-6-phosphate to fructose-1, 6-diphosphate by utilising 2 ATP molecules. This process is known as phosphorylation and it activates the sugar and prevents it from getting out of the cell. Fructose-1,6-diphosphate is then broken down by enzymes to produce two molecules of triose-phosphate (3-carbon sugar), viz., glyceraldehyde-3-phosphate (PGAL) and dihydroxy acetone phosphate. The latter is

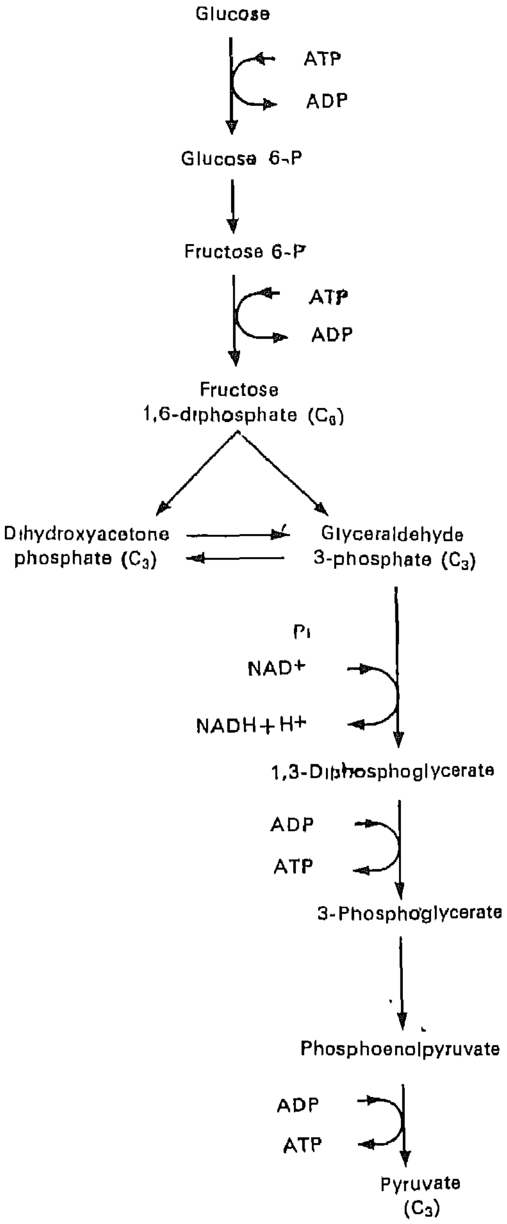

Fig. 10 1 Glycolysis

also converted into PGAL Each PGAL molecule is converted into an intermediate compound 1,3-diphosphoglycerate(DPGAL) by the addition of inorganic phosphate derived from phosphoric acid (H_3PO_4). Thus no ATP is expended in the formation of DPGAL from PGAL DPGAL is then converted into a 3-carbon acid-pyruvic acid ($CH_3CO.COOH$) by oxidation These oxidations release 2 protons (H^+) and 2 electrons (e^-) NAD^+ is reduced to NADH by the addition of 1 proton and 2 electrons Two molecules of ATP are also formed Thus from two triose phosphate molecules, derived from glucose, 4 ATP molecules are produced. Considering that two ATP are spent initially in converting glucose to fructose-1, 6-diphosphate there is a net gain of 2 ATP per glucose molecule metabolised.

Anaerobic Respiration

While studying alcoholic fermentation of glucose by yeast, Pasteur (1860) discovered that it can respire in the absence of molecular oxygen This process is termed anaerobic respiration. Later, it was established that in anaerobic respiration electrons are removed from the substrate during oxidation, but are not finally transferred to molecular oxygen The final electron acceptors are frequently compounds such as pyruvic acid or acetaldehyde, which form a part of the anaerobic respiratory pathway. The end-products are lactic acid or ethanol and not water

In muscles the NADH produced by glycolysis is reoxidised to NAD^+ by donating one proton and two electrons to pyruvic acid which yields lactic acid (Fig 10.2).Skeletal muscles usually derive their energy by anaerobic respiration. After vigorous exercise lactic acid accumulates, leading to muscle fatigue. During rest, however, the lactic acid is reconverted to pyruvic acid and is chanelled back into the aerobic respiration pathway

> In Chapter 5 on small biomolecules you read about the oxygen-storing pigment myoglobin of skeletal muscle fibres. Red (dark) muscle fibres are richer in myoglobin content than the white (pale) muscle fibres Therefore red fibres can utilise the oxygen stored in myoglobin to continue energy production over prolonged periods by aerobic oxidation of glucose. This enables them to perform sustained work over a long period On the contrary, white fibres produce the energy needed for very fast and severe work by glycolysis, mainly because sufficient oxygen is not immediately available to them for such work But white muscles accumulate lactic acid and get fatigued in a short time. Thus athletes with a higher proportion of red fibres in their muscles are physiologically better equipped for sustained events, such as running or swimming over long distances. Athletes with a higher proportion of white fibres in their muscles are equipped for fast, intense, but short activities such as sprint and shot put

In yeast the pyruvate is further changed to acetaldehyde (Fig 10 2) The acetaldehyde then reoxidises NADH and is itself reduced to ethanol. Carbon dioxide is also produced in the process. This type of anaerobic respiration is termed *fermentation*. Accumulation of ethanol by fermentation in a culture of yeast may stop further multiplication and lead to the death of cells In the presence of oxygen, however, yeast can respire aerobically

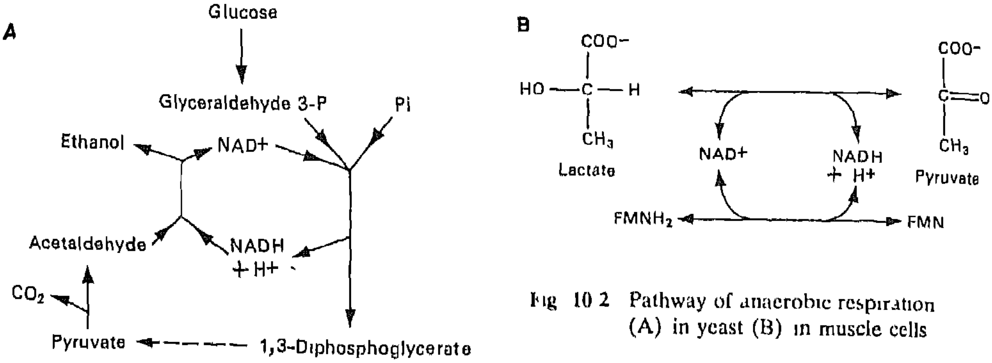

Fig 10 2 Pathway of anaerobic respiration (A) in yeast (B) in muscle cells

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Activities. Anaerobic respiration can be demonstrated by two simple experiments

I A pinch of dry baker's yeast suspended in water or a few ml of yeast suspension used in a bakery is added to about 10 ml of 10 per cent glucose solution in a test tube (Tube A). The surface of the liquid is carefully covered with oil to prevent contact with air (Fig. 10.3) The test tube is closed tightly with a rubber stopper. One end of a short bent glass tube is inserted through it to reach the air inside the tube. The other end of the glass tube is connected by a polyethylene or rubber tubing to another bent glass tube fitted into a stopper The open end of the glass tube (delivery tube) is dipped into lime

Fig. 10.3 Alcoholic fermentation of yeast

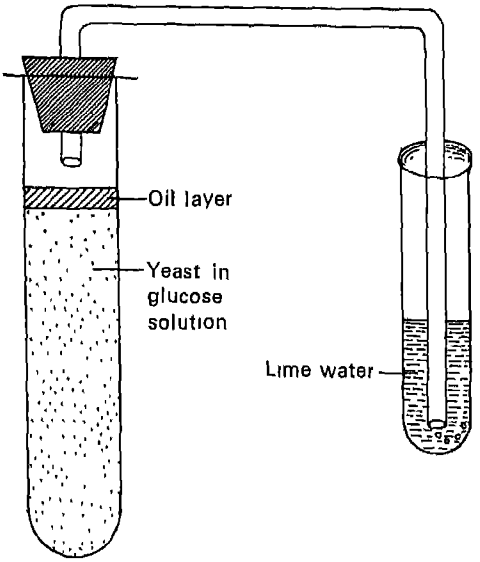
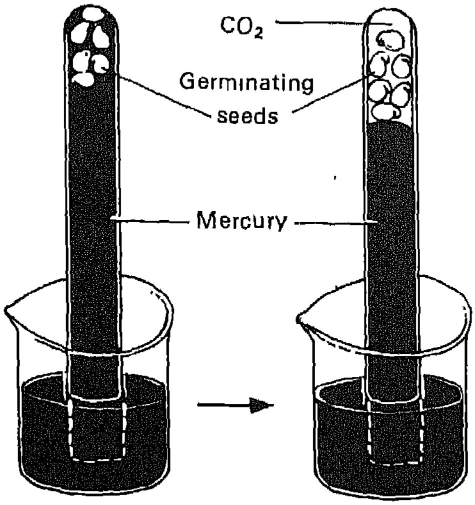


Fig 10.4 Anaerobic respiration of germinating seeds



water contained in a test tube (Tube B) as shown in the figure. The stoppers of both tubes are fitted tightly to prevent leakage of gases The first test tube is placed in warm water (37°C-38°C) in a beaker. The lime water gradually turns milky, indicating the evolution of carbon dioxide from the yeast preparation The level of the lime water in the delivery tube does not rise, showing that there is no decline in volume of gas in test tube A, and consequently no utilisation of oxygen by yeast. The preparation is stored for a day or two. When you open the stopper of tube A you will notice a smell of alcohol indicating the formation of ethanol From this activity it may be inferred that yeast respires anaerobically to ferment glucose to ethanol and carbon dioxide

II. Seed coats of a few germinating seeds (peas, beans or gram) are removed. The seeds are then put in a test tube filled with mercury After closing the test tube with the thumb, it is vertically inverted in a trough of mercury, and the thumb is carefully removed (Fig. 10 4). Being lighter than mercury, the seeds rise to the closed upper end of the test tube. No gas is seen at first in the test tube. As germination proceeds, a gas begins to collect at the top of the mercury in the test tube On introducing a pellet of potassium hydroxide into the tube, it rises to the top and absorbs the gas. The mercury again fills the tube. The potassium hydroxide reacts with carbon dioxide gas to produce potassium carbonate and water. The gas therefore disappears Evidently germinating seeds produce carbon dioxide by anaerobic respiration in the absence of oxygen in the mercury column.

Anaerobic respiration produces less energy than aerobic respiration. There are two reasons for this. (i) The end products of anaerobic respiration can be further oxidised to release energy (ii) The regeneration of NAD does not yield ATP, as the electrons are not transported to oxygen.

Aerobic Respiration

In aerobic respiration molecular oxygen acts as the ultimate acceptor of electrons and protons removed from the substrate For this the cell utilises the oxygen diffusing into it from its surroundings. Aerobic respiration is carried out by the enzymes of the matrix and the inner membrane of the mitochondria. Carbon dioxide produced in the process diffuses out of the cell.

Activities: The following activities may be performed to demonstrate production of carbon dioxide in aerobic respiration.

I. Aerobic respiration of yeast can be demonstrated by using a similar set-up to that used for anaerobic respiration (Fig. 10.3) with two major differences. The container for the yeast culture (test tube or conical flask) should be large enough to leave sufficient space above the glucose solution containing yeast. The surface of the solution should not be covered with oil to permit easy contact with air. Lime water turns milky in this situation also, indicating evolution of carbon dioxide You will note that the level of water in the

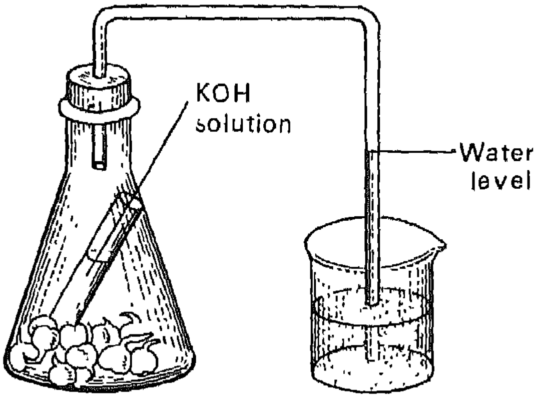


Fig. 10.5 Aerobic respiration of germinating seeds

delivery tube also rises (in test tube B), indicating a fall in gas volume in tube A, because of utilisation of oxygen by yeast. You will not smell alcohol after the reaction in tube A.

II Another set of experiments may be devised using basically similar apparatus, which consists of a conical flask with a rubber stopper fitted with a double bent-glass delivery tube. (Fig 10.5) The living material (flower buds, germinating seeds, insects or earthworms) are put in the conical flask. A small tube containing a 20 per cent potassium hydroxide solution is hung in the flask from the stopper, taking care that it does not spill on the materials The stopper is made airtight. The open end of the delivery tube is dipped in a beaker of coloured water. A control is set up without the living organisms. In the set-up with the organisms the coloured water rises in the tube indicating a fall in gas volume , by respiration and absorption of carbon dioxide. No change is observed in the control.

Aerobic respiration consists of two distinct but mutually dependent processes, the KREBS TRICARBOXYLIC ACID CYCLE (KREBS CYCLE OR TCA CYCLE) which evolves carbon dioxide and in which reduced coenzymes are formed, and the ELECTRON TRANSPORT CHAIN in which the reduced coenzymes are regenerated and oxygen is reduced to water.

Krebs TCA cycle Pyruvic acid produced by glycolysis undergoes aerobic oxidation in the mitochondrial matrix through the TCA cycle. This cycle serves as a common oxidative pathway for carbohydrates, fats and proteins (Fig. 10.6). Moreover, some intermediates of the TCA cycle are used in synthesising important biomolecules such as glutamate and aspartate

Before participating in the TCA cycle, pyruvic acid enters a mitochondrion. Here it is decarboxylated and the remaining 2-carbon fragment is combined with a

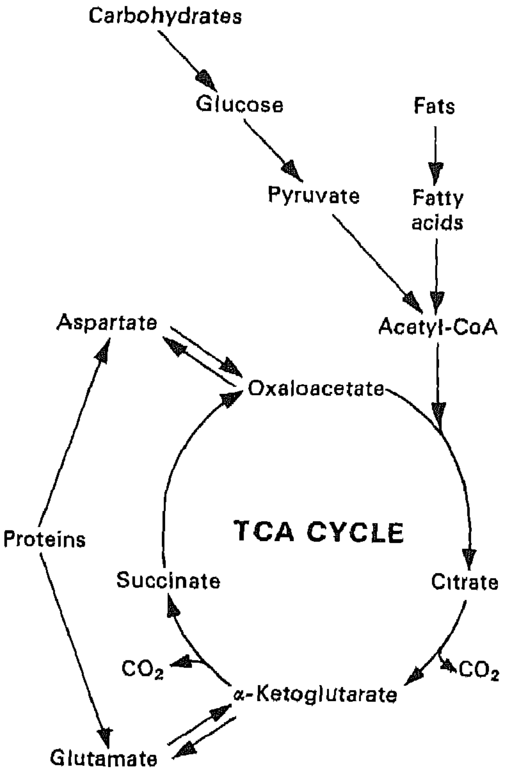


Fig 10.6 TCA cycle as a common metabolic pathway for carbohydrates, fats and proteins

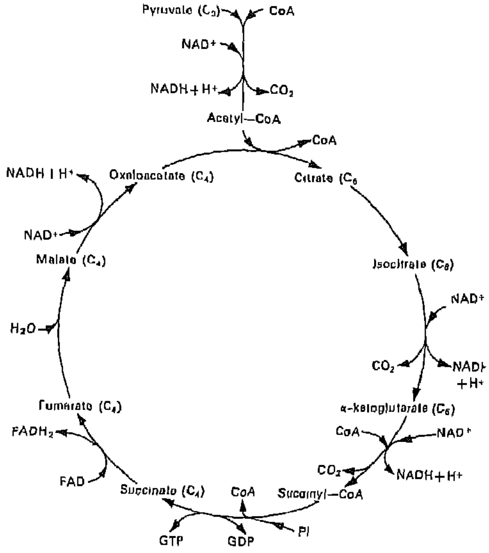


Fig 10.7 Krebs TCA cycle

molecule of coenzyme A to form acetyl-CoA. This reaction is an oxidation-reduction process and produces H ions and electrons along with carbon dioxide During the process NAD is reduced to NADH Beta-oxidation of fatty acids also produces acetyl-CoA as the end product Acetyl-CoA from both sources is condensed with oxaloacetic acid to form citric acid (Fig. 10 7). Citric acid is oxidised stepwise by mitochondrial enzymes, evolving carbon dioxide. This finally regenerates oxaloacetic acid to complete the cycle There are four steps of oxidation in this cycle, catalysed by dehydrogenases (oxidoreductases) using NAD or FAD as the coenzyme The coenzymes are consequently reduced to NADH and FADH respectively These transfer their electrons to the mitochondrial respiratory chain to get reoxidised One molecule of ATP is also produced for every molecule of citric acid oxidised (Fig. 10 7).

Electron Transport Chain

As you have learnt, the H ions and electrons removed from the respiratory substrate during oxidation, do not directly react with oxygen Instead they reduce acceptor molecules such as NAD^+ and FAD to NADH and $FADH_2$ These molecules then transfer their electrons to a system of electron acceptors and transfer molecules. You may recall that some proteins of the inner mitochondrial membrane act as electron-transporting enzymes. They are arranged in an ordered manner in the membrane and function in a specific sequence. This assembly of electron transport enzymes is called the MITOCHONDRIAL RESPIRATORY CHAIN or the ELECTRON TRANSPORT CHAIN (Fig 10.8). Specific enzymes of this chain receive electrons (and in some cases protons also) from reduced prosthetic groups, viz., NADH or $FADH_2$ produced by glycolysis and the TCA cycle. The electrons are then transported successively from enzyme to enzyme, down a descending "stairway" of energy-yielding reactions. At the end of the chain the electrons and the accompanying protons (H^+) are combined with oxygen to form water Oxygen is thus the terminal electron acceptor of the mitochondrial respiratory chain.

> The electron-transport chain includes several cytochromes c, c_1, b, a and a_3. They are all iron-porphyrin proteins. The chain also includes iron-sulphur proteins and a ubiquinone (coenzyme Q). An example of electron flow along the chain is as follows: NADH → FMN (NADH dehydrogenase) → FeS proteins → Co Q → Cy b → FeS proteins → Co Q (?) → Cy c_1 → Cy c → Cy a-a_3 → O.

At each step of electron-transport, the electron acceptor has a higher electron-affinity than the electron donor from which it receives the electrons. The energy from such electron transport is utilised in transporting protons (H^+) from the matrix across the inner membrane to its outer side. This creates a higher proton concentration outside the inner membrane than in the matrix. The difference in proton concentration across the inner membrane is called the PROTON GRADIENT.

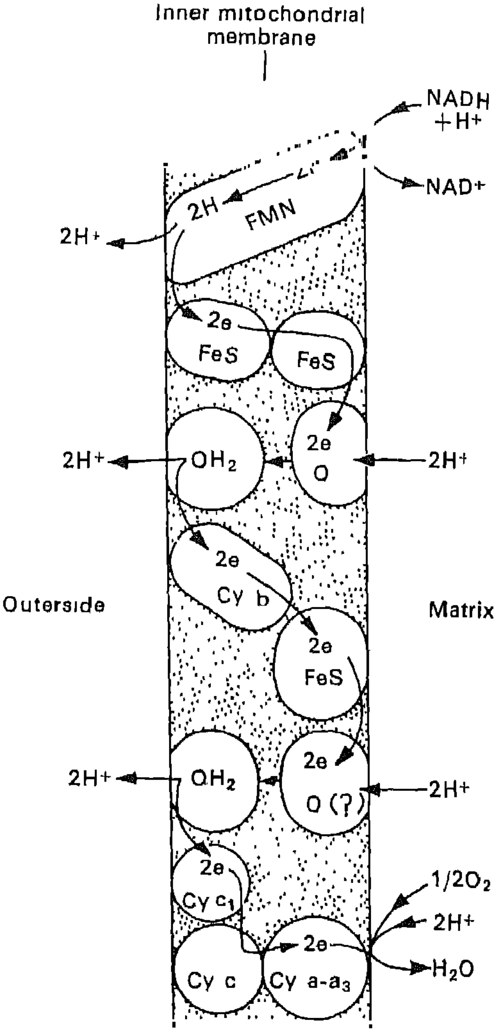


Fig. 10.8 Mitochondrial electron transport chain

Oxidative Phosphorylation

Because of the higher proton concentration outside the inner membrane, protons return to the matrix down the proton gradient. Just as a flow of water from a higher to a lower level can be utilised to turn a water wheel or a hydroelectric turbine, the energy released by the flow of protons down the gradient is utilised in synthesising ATP.

The return of proton occurs through the inner membrane particles In the F_0-F_1 complex, the F_1 head-piece functions as ATP SYNTHASE. The latter synthesises ATP from ADP and inorganic phosphate using the energy from the proton gradient (Fig 10.9).

Transport of two electrons from NADH by the electron transport chain simultaneously transfers three pairs of protons to the outer compartment One high energy ATP bond is produced per pair of protons returning to the matrix through the inner membrane particles Therefore oxidative phosphorylation produces ATP molecules per molecule of NADH oxidised Since $FADH_2$ donates its electrons further down the chain, its oxidation can only produce 2 ATP molecules.

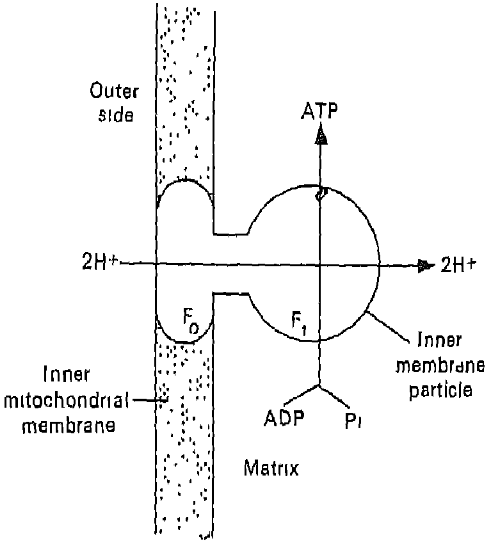


Fig. 10.9 ATP synthesis by inner membrane particles of mitochondrion

What, then, is the outcome of aerobic respiration in terms of ATP generation? We know that glycolysis and TCA cycle can each generate 2 molecules of ATP per molecule of glucose (total 4 ATP) In addition 10 NADH and 2 $FADH_2$ are produced which are equivalent to 34 ATP molecules. Thus a total of 38 ATP molecules are produced per glucose molecule oxidised. In most eucaryotic cells 2 molecules of ATP are required for transporting the NADH produced in glycolysis into the mitochondrion for further oxidation Hence the net gain of ATP is 36 molecules.

Utility of Stepwise Oxidation

You have noted that both anaerobic and aerobic respiration are conducted in many steps. You may wonder what the utility could be of a metabolic pathway with so many steps Such stepwise metabolism serves several purposes (i) A stepwise release of the chemical bond energy facilitates the utilisation of a relatively higher proportion of that energy in ATP synthesis. (ii) Activities of enzymes for the different steps may be enhanced or inhibited by specific compounds. This provides a means of controlling the rate of the pathway and the energy output according to the need of the cell. (iii) The same pathway may be utilised for forming intermediates used in the synthesis of other biomolecules like amino acids.

SUMMARY

Cellular respiration involves diffusion of oxygen into the cell, its utilisation to oxidise glucose, production of carbon dioxide and diffusion of carbon dioxide out of the cell

Cellular respiration may be aerobic or anaerobic. The initial steps, constituting glycolysis, are common to both. Glycolysis results in the conversion of glucose into pyruvic acid. Two molecules of ATP are gained in the process

In anaerobic respiration molecular oxygen is not needed. The electrons removed from the substrates are transferred by the oxidoreductases to electron acceptors other than oxygen. Anaerobic respiration occurs in the cytoplasm Its end-products are lactic acid or ethanol.

Aerobic respiration takes place in the mitochondria and requires molecular oxygen. The process can be divided into two mutually dependent steps, the Krebs tricarboxylic acid cycle and electron transport chain. On entering the mitochondrion pyruvic acid is oxidised to acetyl-CoA Acetyl-CoA enters the TCA cycle, where it is oxidised further, yielding carbon dioxide and reduced coenzymes (NADH and $FADH_2$) The reduced coenzymes are regenerated in the electron-transport chain. The electron transport enzymes of the inner mitochondrial membrane transport the electrons in an ordered sequence to molecular oxygen ultimately producing water. Simultaneously these enzymes transfer protons from the matrix to the outside of the inner membrane, giving rise to a proton gradient The protons subsequently diffuse back to the matrix across the inner membrane particles. The energy released by their flow is utilised to synthesise ATP by the ATP synthase present in the F_0-F_1 complex. The process is termed oxidative phosphorylation The energy trapped in the high energy bonds of ATP is utilised to drive the energy-requiring process.

In aerobic oxidation of one molecule of glucose the net gain of ATP molecules is 36.

QUESTIONS

1. Tick (√) mark the correct answer in each of the following.
   (a) The reactions of the TCA cycle occur in
      i ribosomes
      ii. grana
      iii. mitochondria
      iv. endoplasmic reticulum
   (b) In eucaryotes the complete oxidation of a molecule of glucose results in the net gain of
      i 2 molecules of ATP
      ii 36 molecules of ATP
      iii. 4 molecules of ATP
      iv. 38 molecules of ATP
   (c) The intermediate between glycolysis and TCA cycle is
      i. pyruvic acid
      ii. glucose-1-6-diphosphate

iii. oxalacetate
iv. acetyl-CoA

(d) Mitochondria are called the powerhouses of the cell Which of the following observations supports this statement?
  i mitochondria contain ATP
  ii. mitochondria have a double membrane
  iii. the enzymes of the Krebs cycle and the cytochromes are found in mitochondria
  iv mitochondria are found in almost all kinds of plant and animal cells

2 Fill in the blanks with suitable words
(a) Acetyl-CoA is formed from ______ and coenzyme A
(b) In procaryotes ______ molecules of ATP are formed per molecule of glucose oxidised.
(c) Glycolysis takes place in ______ .
(d) F_1-F_0 particles participate in the synthesis of ______
(e) During glycolysis ______ molecules of NADH are formed

3. (i) When and where does anaerobic respiration occur in man and yeast?
  (ii) Why is less energy produced during anaerobic respiration than in aerobic respiration?
  (iii) Where is the respiratory elecron transport system located in a cell?
  (iv) What compound is the terminal electron acceptor in aerobic respiration?

4 Write explanatory notes on·
(a) glycolysis
(b) fermentation by yeast
(c) electron transport chain

5. Explain the main steps in aerobic respiration
6. How are glycolysis, Krebs TCA cycle and the electron transport chain linked?
7 How would you demonstrate that yeast can respire both aerobically and anaerobically?
8. What is the advantage of step-wise energy release in respiration?

CHAPTER 11

CELL REPRODUCTION

EVERY multicellular organism, be it a microscopic alga, a macroscopic worm, a mango tree or a human being starts as a single cell—the egg. You would expect that to produce billions or trillions of cells as in a whale or an elephant, the organism must have an efficient, nearly perfect mechanism of duplication of cells The way cells divide is fundamentally similar and emphasises the unity of life. In this chapter you will study how cells reproduce

All cells are produced by divisions of pre-existing cells Continuity of life depends on cell division. Somatic cells (body cells) divide by a process called MITOSIS With a few exceptions, about which you will study in Unit Three, germ cells (reproductive cells) divide by the process of MEIOSIS, when they form gametes

Cell Cycle

Each cell capable of division passes through a cycle, the CELL CYCLE The cell cycle of a somatic cell usually consists of a long INTERPHASE followed by a short mitotic or M PHASE (Fig. 11.1). The first part of interphase is called (1) G_1 PHASE. During this phase the cell grows in size and there is an active synthesis of RNA and proteins In this phase the cell carries out its physiological functions and prepares the machinery needed for the cell to proceed to the next stage However it shows no change in its DNA content. In the next phase of the cell cycle called the SYNTHETIC OR S PHASE, the (2) DNA molecule of each chromosome replicates by the synthesis of a new DNA molecule on the template of the existing DNA. Thus each chromosome now carries a duplicate set of genes. Each chromosome is now composed of two sister CHROMATIDS held together by a common CENTROMERE. The cell thus retains the original diploid (2n) chromosome number but now has a duplicate set of genes The third stage of (3) the cell cycle is termed G_2 PHASE. The synthesis of RNA and protein continues in this phase and the cell prepares itself to go into the MITOTIC PHASE. During G_2 a cell contains double the amount (4n) of DNA present in the original diploid cell (2n). The letter G is used to denote the gap between

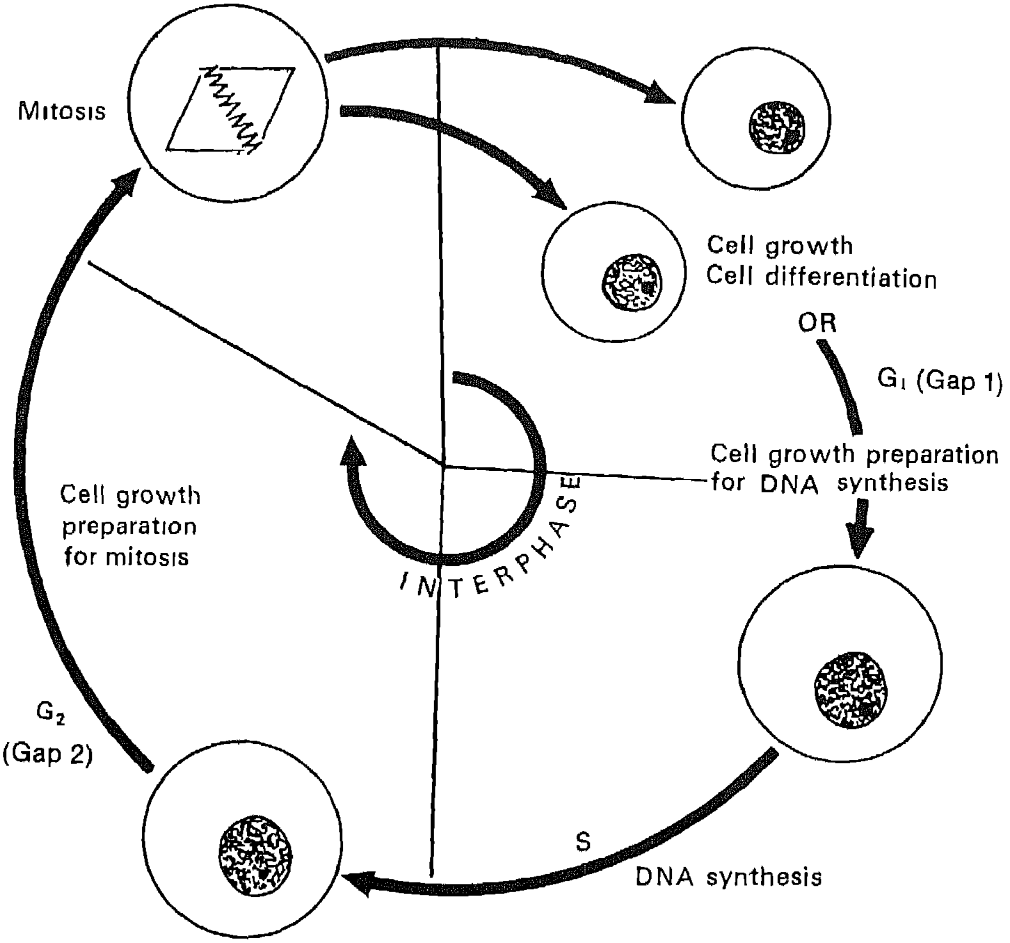


Fig. 11.1 Cell cycle of a somatic cell

the mitotic and the S phase.

Mitosis

During the division of a somatic cell by mitosis two identical daughter cells are formed Separation of chromatids occurs just before the formation of the daughter cells as you will study in a short while. The G_2 phase is followed by division involving nuclear division (KARYOKINESIS) and cytoplasmic division (CYTOKINESIS).

Mitosis is divided into four phases—prophase, metaphase, anaphase and telophase (Fig 11.2). In PROPHASE the chromosomes shorten and thicken progressively and the two sister chromatids are still held together at the centromere. The nucleoli and the nuclear envelope disappear. As prophase progresses, the microtubules form a bipolar spindle The chromosomes move towards the equator of the spindle in the late prophase (prometaphase) In

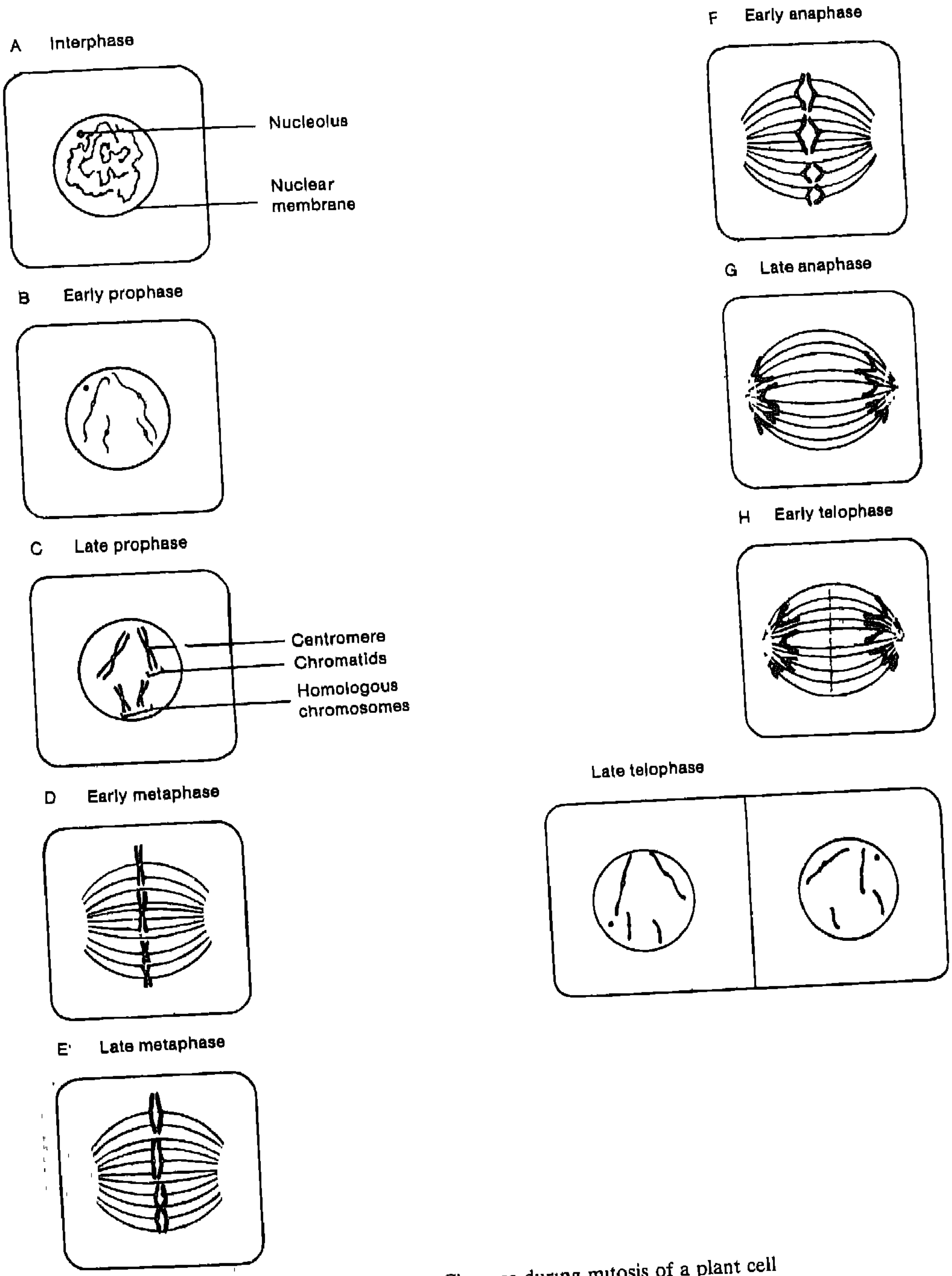


Fig. 11.2 Changes during mitosis of a plant cell

METAPHASE the chromosomes become arranged at the equator of the spindle. The chromosome morphology is best studied at this stage as the chromosomes are most condensed. Each chromosome becomes attached to the spindle fibres at its centromere. In ANAPHASE the sister chromatids of each chromosome separate from one another and pass to the opposite poles of the spindle as daughter chromosomes. This is caused by the division of the centromere and the contraction of the spindle fibres. The original diploid number is thus maintained in the two developing daughter nuclei. In TELOPHASE the nuclear envelope and nucleoli reappear. The spindle disappears and the chromosomes uncoil into the chromatin fibres once again. Thus the nucleus of each daughter cell is reconstituted.

Cytokinesis starts in the telophase. In animal cells a cleavage furrow is formed, which deepens, and finally the cell divides into two daughter cells. Cytokinesis of a plant cell is achieved by the formation of a CELL PLATE instead of a cleavage furrow.

Activity: Take a firm, medium-sized bulb of onion. Trim off the old roots at its base by means of a sharp blade. Place the onion on a conical flask or a bottle full of water with its cut base dipping into it. After a few days you will notice the emergence of a number of new roots. Cut 5 mm off the tips of roots and put them into a vial containing a mixture of 1:3 acetic acid and methanol. Keep for one hour. This process is called fixation. Remove two or three root tips and hydrolyse them by warming to 60°C in 1N hydrochloric acid for 15 minutes. Remove the root tips and wash them thoroughly in water. Place a drop of acetocarmine solution on a slide. Put one hydrolysed root tip in the drop and place a small cover slip on the root. Gently squash the root by tapping the cover slip with the blunt end of a pencil, or a glass rod until the cells separate and spread out into a very thin layer. Make sure that there are no air bubbles under the cover slip. Gently warm the slide over a flame for a few seconds. Observe first under the low power of the microscope to locate the dividing cells which will show deeply stained chromosomes. Examine the different stages of mitosis under the oil immersion lens of the microscope. You may be able to count the number of chromosomes at the metaphase stage.

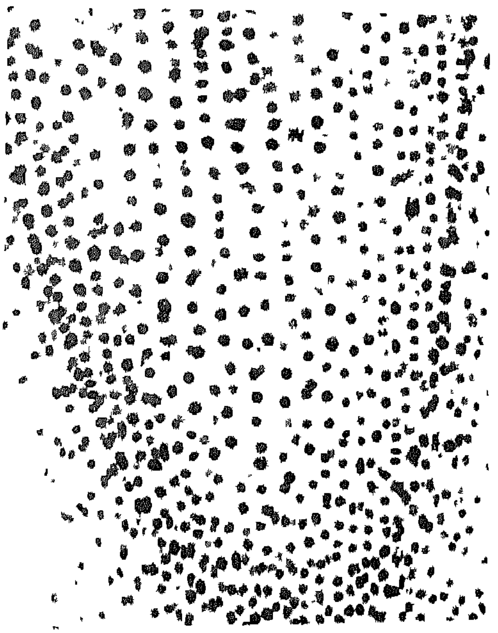


Fig. 11.3 Portion of longitudinal section of onion root tip showing a few cells in mitosis

Significance of Mitosis

You have learnt that in mitosis DNA duplicates in a cell and that the daughter cells inherit an identical gene composition and contain the same number of chromosomes as the parent cell

Somatic cells of a multicellular organism arise from a single cell by mitotic divisions Body growth of a multicellular organism and replacement of its lost cells are accomplished through mitosis Blood cells, intestinal cells and skin cells are regularly replaced in large numbers by mitoses of respective parent cells.

COLCHICINE—THE MITOTIC POISON

The alkaloid colchicine, obtained from autumn crocus *Colchicum autumnale*, is a poison of cell division. It inhibits the formation of mitotic spindle The chromosomes duplicate but they remain within the same cell, increasing the number of chromosomes. Such cells are called polyploid cells. Plant breeders have used colchicine-induced polyploidy as a means of producing variants of agricultural and horticultural crops.

Meiosis

In all sexually reproducing diploid organisms the male and female germ cells divide meiotically to produce the male and female gametes respectively Meiosis comprises two successive divisions, Meiosis I and Meiosis II, and results in the formation of four daughter cells (Fig. 11.4). You have just learned that in mitosis two daughter cells are formed.

MEIOSIS I is also called reduction division as the chromosome number is halved. It is divided into prophase I, metaphase I, anaphase I and telophase I

Prophase I. This complex phase is usually subdivided into five stages (Fig 11.4)

(a) Leptonema · Progressive condensation and coiling of chromatin fibres occurs at this stage The chromosomes appear at first as fine single threads They contract and become thick

(b) Zygonema. Each diploid nucleus has pairs of similar chromosomes (HOMOLOGOUS CHROMOSOMES) T [illegible] chromosomes each derived from one parent during sexual reproduction now come together and form pairs. Individuals of a pair are similar in length and in position of their centromere

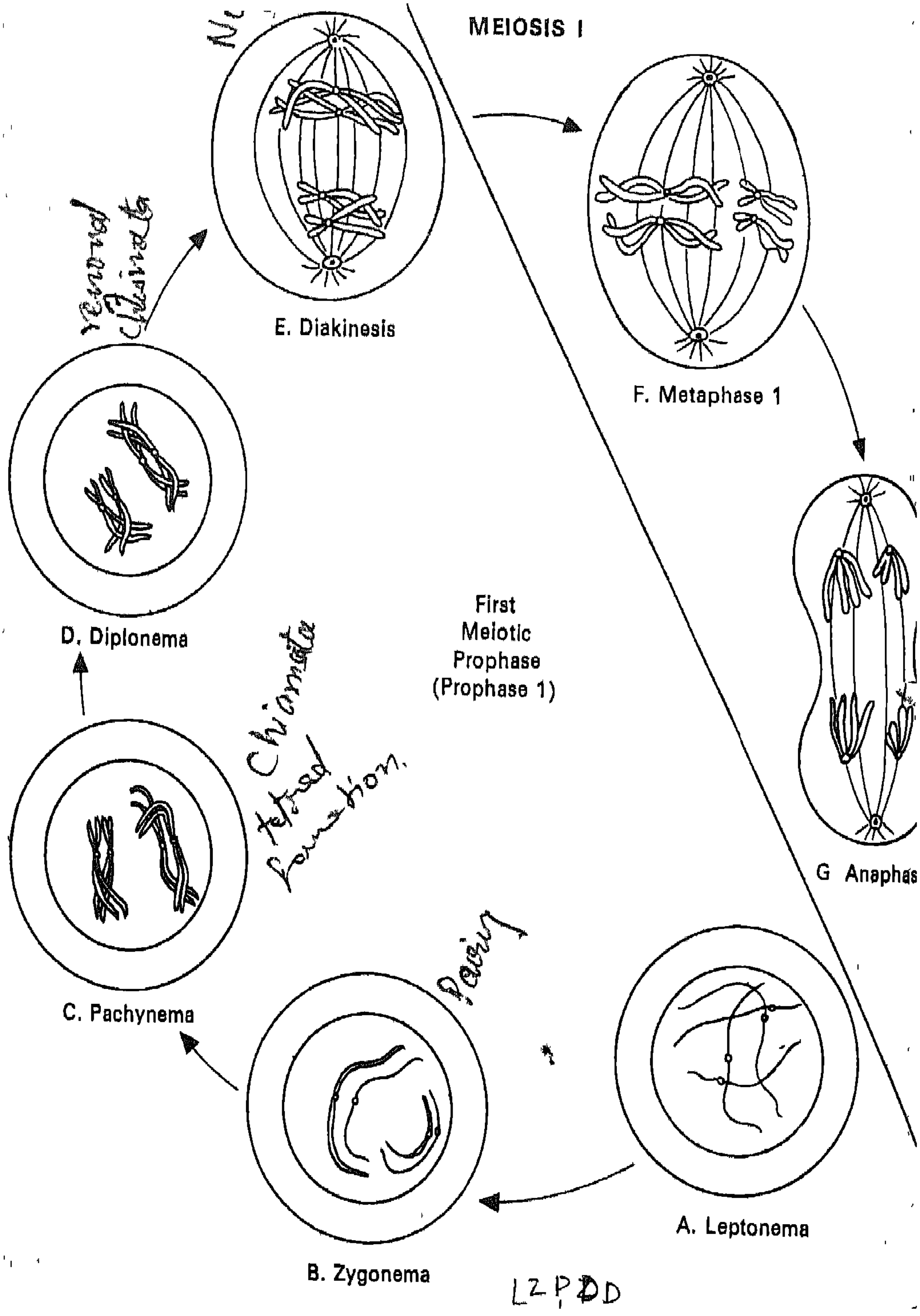
(c) Pachynema. The paired chromosomes are now called bivalents They become still shorter and thicker. At this stage two sister chromatids of each homologue become visible and the bivalent thus becomes a tetrad with four chromatids Genetic material is exchanged between non-sister chromatids (of the homologues) by breakage and rejoining This process is known as CROSSING OVER. The regions where crossing over takes place are called CHIASMATA (singular CHIASMA).

(d) Diplonema Homologous chromosomes continue to condense. The two chromosomes of each bivalent move away from each other and the chiasmata finally disappear

(e) Diakinesis The nucleolus and nuclear envelope disappear and a spindle begins to be formed at the end of this stage

Metaphase I · The spindle formation is completed and the bivalents arrange themselves at the equator of the spindle

Anaphase I: The two chromosomes of each bivalent separate from one another and pass to the opposite poles of the spin-


MEIOSIS I
Ne
E. Diakinesis
F. Metaphase 1
removal Chiasmata
D. Diplonema
First Meiotic Prophase (Prophase 1)
Chiamata tetrad formation.
G Anaphas
C. Pachynema
Pairing
A. Leptonema
B. Zygonema
LZPDD

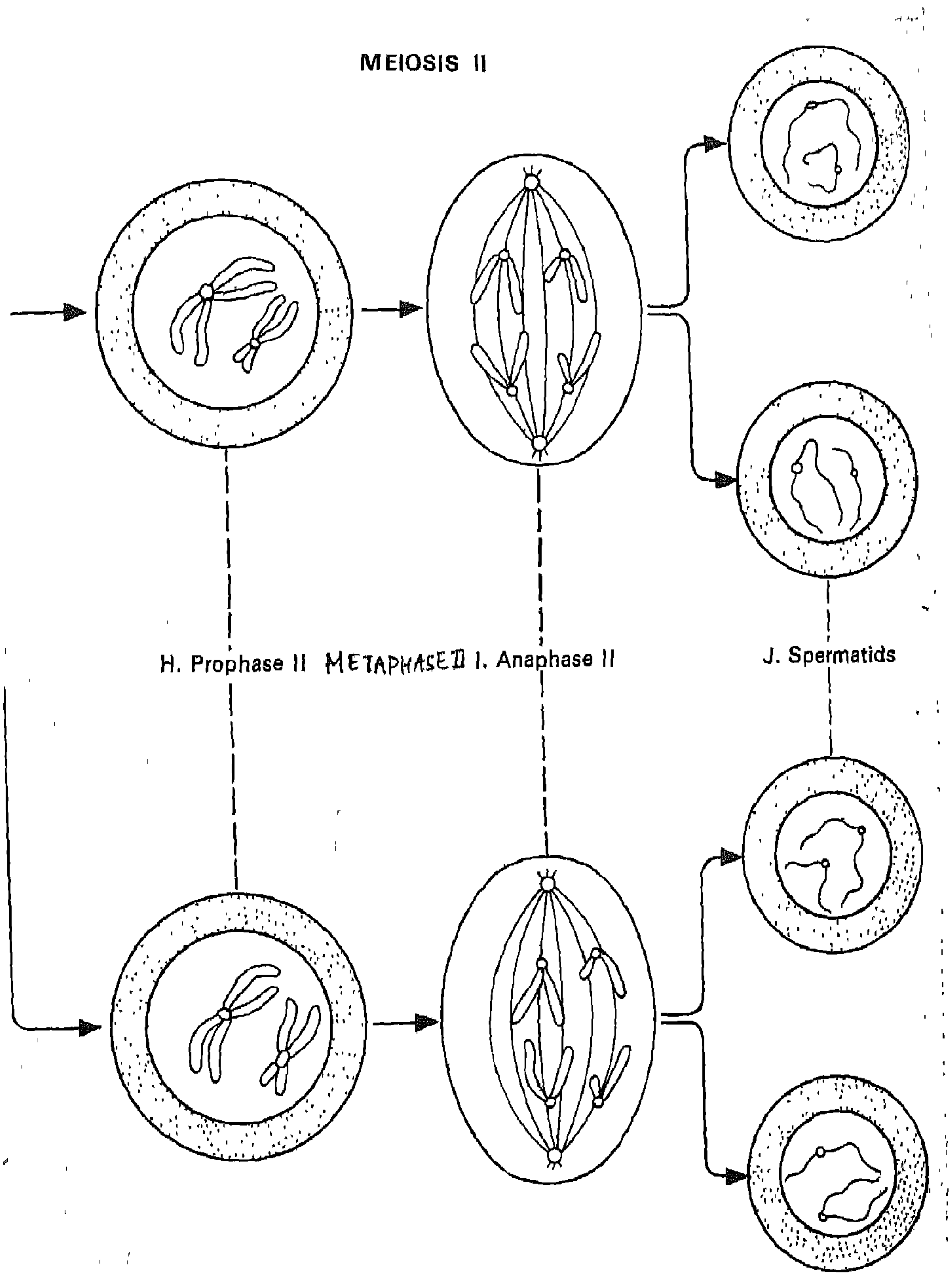


Fig. 11.4 Stages in meiosis I and II of a spermatozoid mother cell. Four haploid spermatids are formed.

dle. But the two chromatids of each chromosome still continue to remain joined with each other at the centromere Thus only ONE chromosome of each homologous pair reaches each pole. Consequently the nucleus of each daughter cell gets only HALF the number (haploid) of chromosomes present in the original cell.

Telophase I : The nuclear envelope forms again around the chromosomes at each pole. This is generally followed by cytokinesis to form two haploid (n) daughter cells (also called dyad).

A short interphase, termed INTERKINESIS, may intervene between meiosis I and meiosis II. However, replication of DNA does not occur in this phase Sometimes, the daughter nuclei are not fully constituted in telophase I Instead, the chromosomes reaching each pole may progress directly to prophase II

Meiosis II is similar to mitosis and is also called equational division. It consists of prophase II, metaphase II, anaphase II and telophase II.

Prophase II : Sister chromatids of each chromosome begin to condense.

Metaphase II : A bipolar spindle is formed. The haploid number of chromosomes become arranged at the equator of the spindle. Each chromosome will have two chromatids held together at the centromere.

Anaphase II : The centromeres separate and the sister chromatids of metaphase II move as daughter chromosomes to the two poles.

Telophase II : The chromosomes begin to uncoil (stretch) and become thin. The nuclear membrane and the nucleoli are reconstituted.

Cytokinesis occurs and the two nuclei are separated. Each daughter cell of meiosis I thus produces two haploid daughter cells at the end of meiosis II In other words, the products of meiosis of a diploid cell are four haploid daughter cells (gametes)

Significance of Meiosis

In preparation for sexual reproduction haploid male and female gametes are produced. During fertilisation one male gamete (sperm) fuses with a female gamete (egg). Nuclear fusion restores the original diploid chromosome number in the zygote, which gives rise to the offspring This mechanism ensures the maintenance of the same chromosome number characteristic of the species from generation to generation

The crossing over of chromosomes in meiosis leads to the production of four daughter cells, differing slightly from one another, as also from the parent cell in their genetic constitution. Thus meiosis results in variations of genetic character in the offsprings.

THE ENIGMA OF CANCER

What factors regulate cell division is not clearly understood It is believed that the body somehow regulates the pace of cell multiplication. Uncontrolled cell division in certain tissues and organs (bone marrow, lung, breast, etc.) leads to cancer. Certain types of radiation, chemicals formed during smoking, toxic substances produced by automobiles and chemical industries, are considered causative agents of cancer. Cancer is also shown to be enhanced by components of human diet, certain viruses and hereditary predisposition. There is recent evidence that specific genes (oncogenes) are associated with cancer. Radiotherapy, chemotherapy and surgery are used to check cancer at early stages. However, no cure for cancer has yet been developed. Probably no other human disorder has received so much attention from biologists and other scientists as cancer. The understanding and treatment of cancer illustrate one of the most difficult areas in the history of science. Despite the application of the scientific method, efforts by thousands of eminent and dedicated scientists, with the best tools and techniques at their disposal, cancer still remains a challenge

SUMMARY

Cells replicate by cell division Somatic cells divide by mitosis. In diploid organisms gamete production is by meiosis In the S phase of each interphase nucleus before mitosis, replication of DNA takes place The S phase is preceded and succeeded by the G_1 and G_2 phases respectively During these two phases RNA and protein are synthesised The mitotic phase follows the G_2 phase During mitosis the nuclear membrane disappears and a mitotic spindle is formed Two sister chromatids of each chromosomes are held together by the centromere, Chromosomes get arranged at the equator of the spindle. Then the two chromatids separate from one another and pass to opposite poles of the spindle and become daughter chromosomes The nucleus is reconstituted at each pole. In animal cells cytokinesis occurs by the formation and extension of the cleavage furrow In plants cytokinesis is by the formation and extension of the cell plate. The importance of mitosis lies in the fact that it helps unicellular organisms to increase their number and in multicellular organisms to produce a vast number of cells with similar genetic constitution, which make up their structure It is also useful for the replacement of lost cells

Germ cells divide meiotically to produce gametes. In the interphase, the amount of DNA is doubled During meiosis I, or reduction division, homologous chromosomes form pairs called bivalent. There is exchange of genetic material between non-sister chromatids (of the homologues) by chiasma formation and crossing over The two chromosomes then separate and move to the opposite poles of the spindle Thus two haploid cells are formed from a diploid cell This is followed by a short interkinesis, with no further replication of DNA Meiosis II which follows has steps similar to mitosis and is called equational division Thus four haploid cells are formed from a single diploid cell during meiosis The diploid number is restored when haploid gametes fuse during fertilisation The importance of meiosis lies in the fact that it offers a machanism for obtaining genetic variation It also keeps the chromosome number constant from one generation to the next.

QUESTIONS

1. Fill in the blanks with suitable words.
   (a) Somatic cells multiply by ____________
   (b) Mitosis results in the formation of nuclei having ____________ number of chromosomes

(c) The second division of meiosis may be described as ______________ division
(d) The region of the attachment of chromosomes to spindle fibres is called ______________.
(e) In meiosis haploid condition is reached by ______________ stage

2 Which of the following statements is associated with A Prophase B. Metaphase C. Anaphase D Telophase E Interphase of mitosis?
(a) The nuclear membrane reappears
(b) Chromosomes are thickest and shortest
(c) Chromosomes begin to coil
(d) Centromere divides into two
(e) Nucleus is active but chromosomes are not distinct
(f) Followed by cytokinesis
(g) Each chromosome consists of two chromatids

3 Supply a specific scientific term for each of the following
(a) The period between two successive mitotic divisions
(b) Process of cell division by which the chromosome number is halved
(c) Point at which two sister-chromatids are held together
(d) Phase in the cell cycle when protein and RNA are synthesised
(e) Nuclear division

4. Tick (√) mark the correct answer in each of the following
(a) In the meiotic cell division 4 daughter cells are produced by two successive divisions in which
  i. First division is equational, second is reductional
  [✓ ii. First division is reductional and second is equational]
  iii. both divisions are reductional
  iv both divisions are equational
(b) The two daughter-cells formed during mitosis contain
  i. the same amount of DNA, but a set of chromosomes different from those of the parent cell
  [✓ ii. the same amount of DNA and the same set of chromosomes as those of the parent cell]
  iii. half the amount of DNA and the same set of chromosomes as those of the parent cell
  iv double the amount of DNA and a set of chromosomes different from those of the parent cell.

5. Name and explain the three stages of cell cycle associated with interphase.
6 Describe the changes occurring in the nucleus during prophase of mitosis
7. What are the main differences between mitosis and meiosis?
8 Explain the significant of meiosis
9. Plant X has 2n = 8 chromosomes. Sketch the various stages of meiosis in this plant.
10 What are homologous chromosomes? What happens to homologues during meiosis?
11. Anaphase I of meiosis differs from anaphase of mitosis in one essential way. Describe the difference and explain how it affects the daughter cells.
12 Why does a multicellular organism require two types of cell division? Which of the two produces the greater number of cells?
13 A well-known biologist stated that the life history of an organism can be summed up as "gametic fusion, equational division and reductional division " Comment

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